ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

Course: - Construction Materials

Objectives of the course:

The major objective of the course is to study the production processes and properties of different construction materials in civil engineering practices. More emphasis will be given to concrete making materials and alternative ways of mix design procedures will be discussed.

Course outline

1. Mechanical properties of materials
    - Testing of materials for mechanical properties
    - The tension test
    - The compression test
    - The shear test:
    - The bending test: Properties for the elastic and plastic range
    - Relationship b/n material properties

2. Cementing Materials
    - Production and uses of lime, gypsum and cement
    - Types and properties of cement
    - Hydration of cement
3. Mortar, concrete making materials and plain concrete
    - Physical and mechanical properties of aggregates
    - Concrete classes Concrete admixtures
    - Mix design methods and curing techniques
    - Fresh and hardened concrete properties
    - Quality control of concrete

4. Ferrous and non-ferrous materials Properties of steel and aluminum alloys

5. Timber and Timber products

Laboratory Exercises CENG-2111

Lab. Exercise

Description of the activity

Activity 1

1.1 Laboratory facility demonstration

1.2 Different types of construction materials used in Ethiopia

Activity 2

2.1. Loose unit weight of cement

2.2. Normal consistency of cement

2.3. Setting time of cement (initial and final)

2.4. Setting time of gypsum

Activity 3

3.1 Silt test by weight and volume

3.2 Workability or mortar and compo-mortar

3.3 Casting of mortar and compo-mortar cubes

Activity 4

4.1 Compressive strength of mortar and compo-mortar

4.2 Sampling techniques of aggregates:

4.3 Sieve analysis of fine and coarse aggregates

Activity 5

5.1 Moisture content and absorption capacity of fine aggregates

5.2 Moisture content and absorption capacity of coarse aggregates

5.3 Bulking of sand

Activity 6

6.1 Concrete mixing

6.2 Workability of concrete by using slump test

6.3 Casting of concrete cubes and prism

Activity 7

7.1 Test for compressive strength of concrete

7.2 Test for physical properties of bricks and hollow blocks

7.3 Efflorescence of bricks

7.4 Compressive strength of bricks, HCB and concrete blocks

Activity 8

8.1 Tension test of reinforcement bar

8.2 Flexural strength of concrete and timber

CHAPTER 1: MECHANICAL PROPERTIES OF MATERIALS

Introduction

Properties which relate to materials generally are Physical properties and chemical properties. Physical properties include density and specific gravity, thermal properties and acoustical properties. Chemical property includes corrosion.

The mechanical properties of materials are important to engineers allowing the selection of the proper material and design in order to avoid or at least minimize failure. When forces are applied to a solid body in equilibrium two results are generally produced:

i. Internal resisting forces are developed in the body which balance the external applied forces. These internal forces are called stress.

ii. The body is deformed to a varying degree and this deformation is called strain.

The properties of materials when subjected to stresses and strains are called “mechanical properties”. The response of a material to applied forces depends on the type and nature of the bond and the structural arrangement of atoms, molecules or ions. Depending on the arrangement and direction of the external forces, the stress produced in a body may be tensile stress, compressive stress, shearing stress, bending stress, torsional stress, and various combination.

Basic deformation types are

i. Elastic deformation: after the application and removal of load, returns to its original size and shape.

ii. Plastic deformation: after the application and removal of load the body fails to return to its original size and shape.

Testing of materials for mechanical properties

Mechanical tests are those used to examine the performance of construction materials under the action of external forces. Standardization is necessary in order to make test results comparable wherever or by whomsoever they are made. Mechanical tests may be classified under several headings:

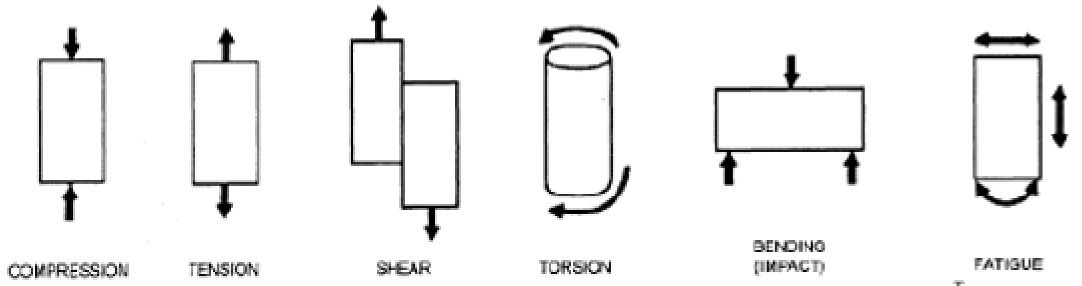
Type of tests with reference to the arrangement and direction of the external forces include:

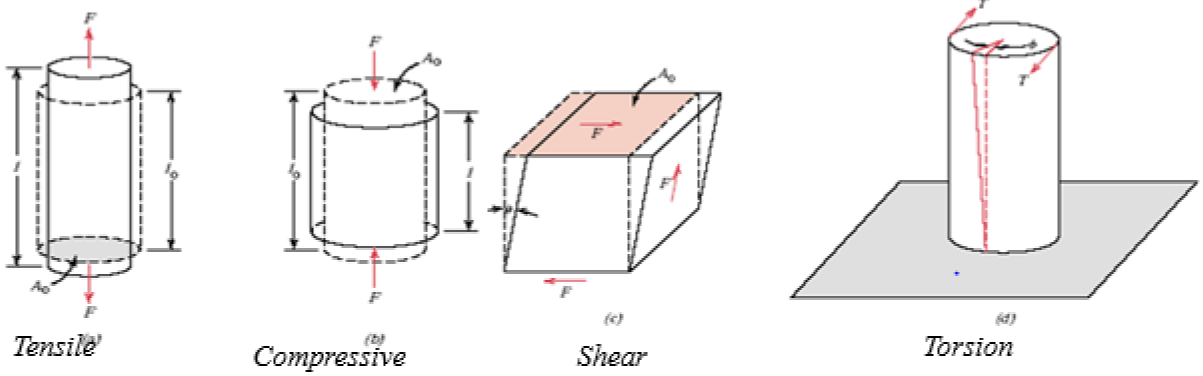
a. Tension test: A specimen under tension test is subjected to an axial tensile force. (pulling)

b. Compression test: A specimen under compression test is subjected to an axial compressive force.(pushing)

c. Shear test: the shearing stress in a specimen is determined on cross sectional areas parallel to the line of action of the external forces which are themselves parallel. (shoving/sliding)

d. Bending test: a specimen under bending is subjected to forces that give rise to bending moments. e. Torsion test: An indirect test used to determine the shearing strength of a material.





II. Type of tests with reference to the rate and duration of the load application:

   a. Static tests: Tests are made with gradually increasing load, such as the ordinary test in compression, tension, etc.

   b. Dynamic tests: These are made with suddenly applied loads, as by failing weight or pendulum. E.g. Drop impact test.

   c. Wear tests: These are made to determine resistance to abrasion and impact. E.g. Los Angeles abrasion test, attrition test, etc.

   d. Long-time tests: These are made with loads applied to the object under test for long period of time.

   e. Fatigue tests: These are made with fluctuating stresses repeated a large number of times

III. Type of tests with reference to the effect of the test on the specimen:

a. Destructive tests: Under these test methods the specimen are either crushed or ruptured and made useless at the end of the tests. E.g. Tensile test for reinforced bar, compression test for concrete.

b. Non-destructive tests: These are usually used to test the strength of members of existing structures with out affecting their performance. E.g. Rebound hammer test of concrete structures.

Destructive tests b) Compressive test

Destructive tests a) Bending test

The tension test

The tension and compression test are used to provide basic design information on the strength of materials and as an acceptance test for the specification of materials. Nominal stress strain properties in simple tension is related using the following formula.

❑ Stress:

$$\sigma = \frac{F}{A_0}$$

Where:
σ = the tensile stress
F = applied load
A_0 = area of the section perpendicular to the line of action

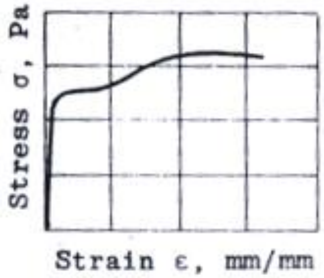
❑ Strain:

$$\epsilon = \frac{l_i - l_0}{l_0} = \frac{\Delta l}{l_0}$$

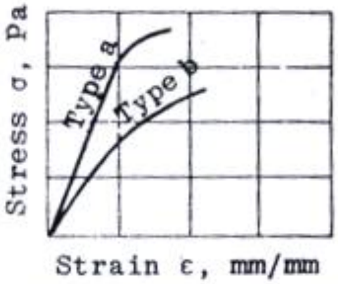
Where:
ε= strain
Δl= total elongation
l_0 = original length of specimen

Nominal stress strain properties in simple tension

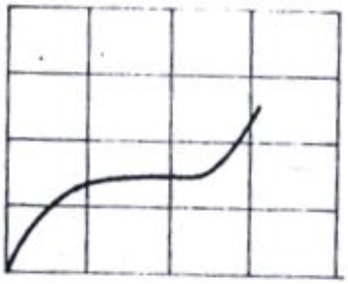
With the values of the stress σ and strain ε, the stress-strain diagram can be plotted. The amount of deformation. Some common types of nominal stress-strain diagram which the material will undergo before rupture varies widely with different materials:



(a) Ductile material



(b) Britt.e material



c) Non-metallic elastic material (soft rubber)

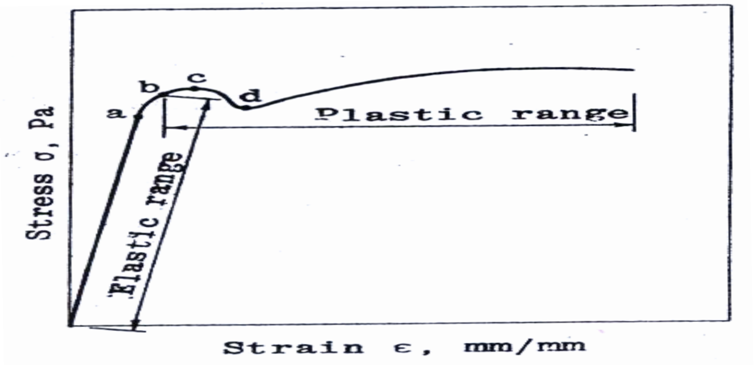
The initial stress-strain relation is assumed to be linear and can be represented by the equation:

$$\sigma_t = E\varepsilon \quad \text{or} \quad E=\frac{\sigma_t}{\varepsilon}$$

$$E=\frac{(P/A_o)}{(\Delta l/L_o)}$$

$$E=\frac{PL_o}{A_o\Delta l}$$

The stress-strain relation given in the above equation is known as Hooke's law. E, the slope of the straight line, is called the modulus of elasticity.



Elastic and Plastic strains for ductile material.

Properties for the elastic range

The parameters which are used to describe the mechanical properties of material for the elastic range are:

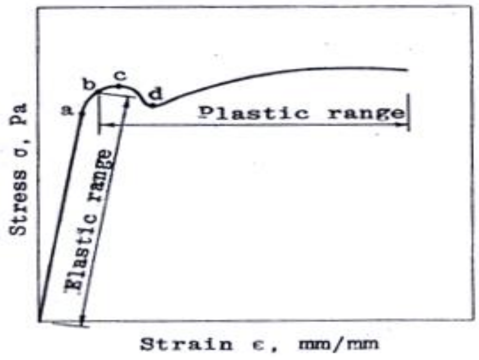
A. Proportional limit: also called proportional elastic limit is the greatest stress which a material is capable of withstanding without a deviation from the law of proportionality (Point a).

B. Elastic limit: is the greatest stress which a material is capable of withstanding without a permanent deformation remaining upon release of stress (Point b).

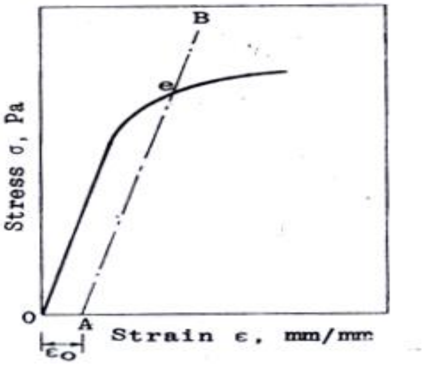
C. Elastic strength: is measured by the stress which represents the transition from the elastic range to the plastic range (points a to d).

D. Yield point: is the stress at which there occurs marked increase in strain without an increase in stress. Only ductile materials have yield point (upper (c) and lower (d) yield points).

E. Yield strength: is the stress at which yielding occurs. The stress-strain relations of most materials do not show specific yield points; hence other means are used to define the yield strength and consequently the elastic strength.



Elastic and Plastic strains for ductile material.



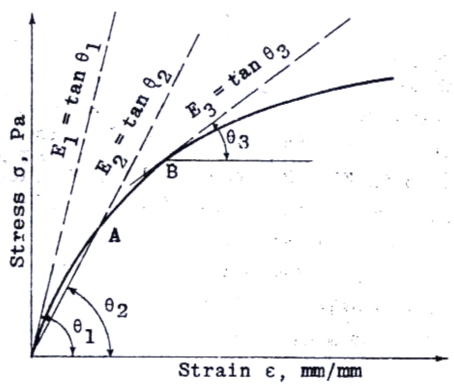
Determination of elastic strength for materials.

f. Modulus of elasticity: also known as young's modulus, is the slope of the initial linear portion of the stress strain curve. Three different methods are employed to define the modulus of elasticity for materials with curved stress-strain diagrams. These are:

i. Initial tangent modulus

ii. Secant modulus

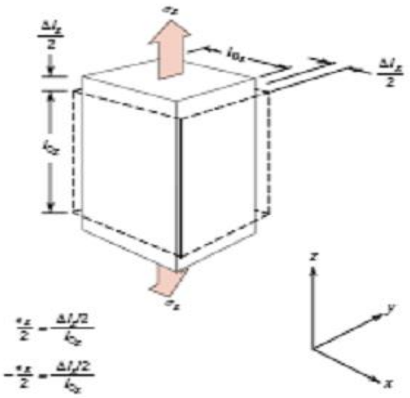
iii. Tangent modulus



Determination of modulus of elasticity for materials with non linear stress-strain curves

g. Stiffness: The stiffness of a material is measured by its modulus of elasticity. The higher the modulus, the stiffer the material. E.g. E_{Steel}=210GPa, $E_{Almunium}$ = 70GPa.

h. Poisson's ratio: is the measure of the stiffness of the material in the direction at right angles to the applied uniaxial tensile stress. Most metals have a value of Poisson's ratio b/n 0.25 and 0.35.



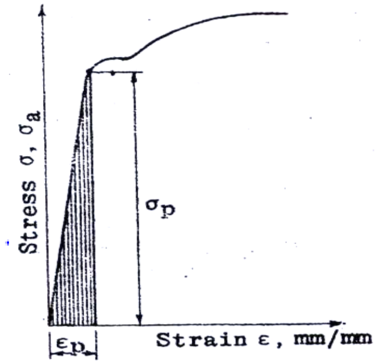
$$\varepsilon_x = \varepsilon_y \qquad \nu = -\frac{\epsilon_x}{\epsilon_z} = -\frac{\epsilon_y}{\epsilon_z}$$

i. Resilience: is the ability of a material to absorb energy when deformed elastically and to return it when unloaded. Resilience is measured by the modulus of resilience. Modulus of resilience is the internal work or strain energy per unit volume required to stress the material from zero stress to proportional limit.

$$R=\frac{1}{2}\sigma_p.\varepsilon_p$$

$$=\frac{1}{2}\sigma_p.\frac{\sigma_p}{E}$$

$$=\frac{\sigma_p^{\,2}}{2E}$$



For a specimen of cross sectional area A and length L, the total elastic strain energy in axial loading can be obtained as the product of modulus resilience and its volume.

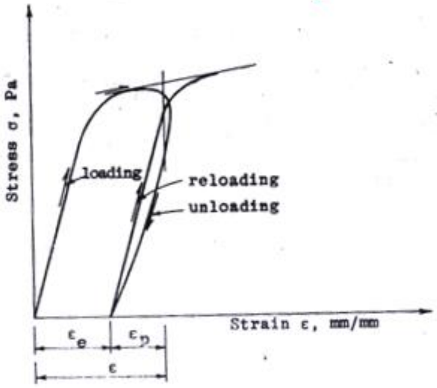
$$u=\frac{\sigma_p^{\,2}}{2E}.AL=\frac{P^2}{2A^2E}.AL=\frac{P^2L}{2AE}$$

Properties for the plastic range

A permanent deformation remains in the stressed body after complete removal of the load. The strain at this stage is made up of two parts: a recoverable elastic strain ε_e and a non recoverable plastic strain ε_p.

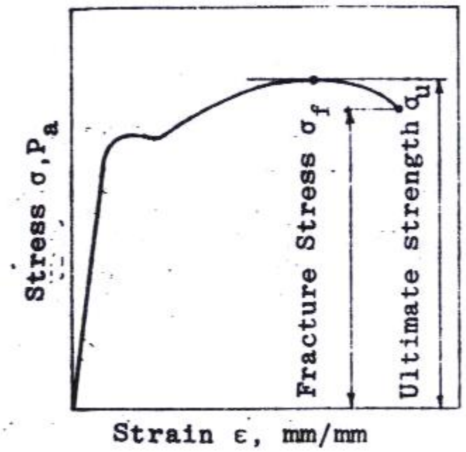
$$\boxed{\begin{aligned}\varepsilon&=\varepsilon_e+\varepsilon_p\\&=\frac{\sigma}{E}+\varepsilon_p\end{aligned}}$$

Elastic & plastic strain

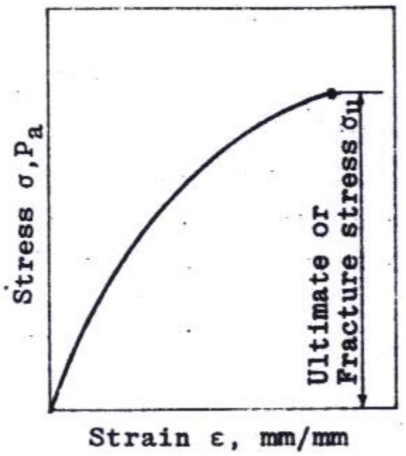


The parameters which are used to describe the mechanical properties of material for the plastic range are:

a. Plastic strength: the plastic strength of a material is the maximum stress a material can possibly resist just before failure. The plastic strength will correspond to the ultimate strength (ultimate stress) or to the fracture (rupture) strength.



(a) Ductile material



(b) Brittle material

b. Ductility: ductility of a material represents its ability to deform in the plastic range. Ductility is usually measured by the percentage elongation, which is the percentage strain corresponding to rupture.

$$\boxed{D_e = \frac{L_f - L_o}{L_o}\, 100 \qquad \text{or} \qquad D_e = \varepsilon_f \, x100}$$

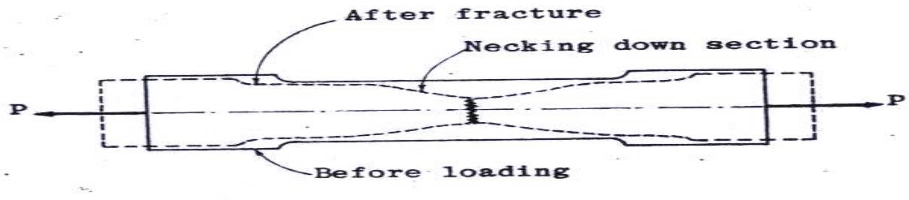
Where:

D_e = Percentage elongation, ductility

L_o = original length of specimen

L_f = length of specimen at rupture

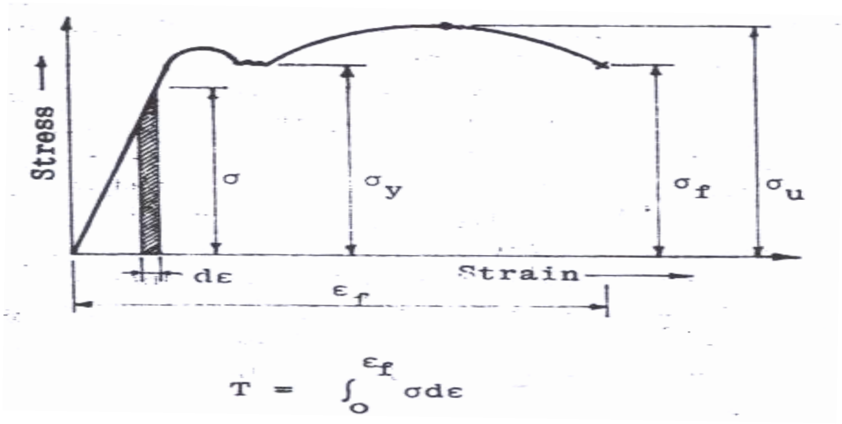
ε_f = unit strain at rupture



Ductility is also measured by the percentage reduction in area.

$$\%RA = \left(\frac{A_0 - A_f}{A_0}\right) \times 100$$

c. Toughness: the toughness of a material is its ability to absorb energy in the plastic range. It is measured by the modulus of toughness or the amount of energy absorbed per unit volume in stressing to fracture.



For certain ductile material the toughness can be approximated by toughness index number or merit number.

$T_D = \sigma_u \varepsilon_f$ or $T_D = \varepsilon_f (\sigma_y + \sigma_u)/2$

For brittle materials with parabolic stress-strain curve the modulus of toughness becomes

$T_b = \sigma_u \varepsilon_f$

Where:

σ_y = Stress at yield point

σ_u = Ultimate stress

ε_f = Unit strain at fracture

Excercise-1

Determination of mechanical properties in tension for a ductile material

A specimen with a diameter of 12mm and gage length of 50mm was used in a standard tension test of structural steel. The load at the lower yield point was found to be 32 kN. The Maximum and fracture loads were 54 kN and 38 kN respectively and the gage length at fracture was 64.118mm. The diameter of the fracture cross-section was found to be 8.910 mm. At a load of 15.161 kN the total strain was 0.0336mm. A plot of the stress-strain diagram showed that the initial straight-line part of the diagram passed through the point of zero stress and strain. Determine: (a) the lower yield point, (b) the modulus of elasticity, (c) the modulus of elastic resilience, (d) the ultimate stress, (e) the fracture stress, (f) the percentage elongation, (g) the percentage reduction in area, and (h) the toughness index number.

Solution

Original Cross-sectional area of specimen:

$$A_o = \frac{\pi(12)^2}{4} = 113097\ \text{mm}^2$$

a) Therefore, the lower yield point (stress) becomes

$$\sigma_y = \frac{P_y}{A_o} = \frac{33 \times 10^3}{11.097} = 283\ \text{N/mm}^2$$
$$= 283\ \text{MPa}$$

b) From Eq.2.4, the modulus of elasticity is

$$E = \frac{\sigma}{\varepsilon} = \frac{PL_0}{A_o\Delta_f} = \frac{(15.161 \times 10^3)50}{113.09 \times 0.0336} = 199{,}848\ \text{N/mm}^2$$
$$= 199{,}49\ \text{MPa}$$

c) From Eq. 2.6, the Modulus of elastic resilience is:

$$R = \frac{\sigma_p^2}{2E} = \frac{\sigma_y^2}{2E} = \frac{(283)^2}{2 \times 199{,}484} = 0.201 \text{ N.mm per Cu.mm}$$

d) Ultimate stress

$$\sigma_u = \frac{P_u}{A_o} = \frac{54 \times 10^3}{113.097} = 477.466 \text{ N/mm}^2$$
$$= 477.47 \text{ MPa}$$

e) Fracture stress

$$\sigma_f = \frac{P_f}{A_o} = \frac{38 \times 10^3}{113.097} = 335.90 \text{ MPa}$$

f) From Eq. 2.10 the percentage elongation is

$$D_c = \frac{L_f - L_o}{L_o} 100 = \frac{64.118 - 50}{50} \times 100 = 28.24\%$$

g) Area at fracture

$$A_f = \frac{\pi(8.910)^2}{4} = 62.351 \text{ mm}^2$$

Therefore, the percentage reduction in area is

$$D_a = \frac{A_o - A_f}{A_o} 100 = \frac{113.097 - 62.351}{113.097} \times 100 = 44.87\%$$

h) Toughness index number

$$T_D = \sigma_u \varepsilon_f = 477.466 \times 0.2824 = 134.836 \text{ N.mm per Cu.mm}$$

Excercise-2

Determination of mechanical properties in tension for a brittle material

A cast iron tension specimen has a gage length of 50mm and a diameter of 12mm. The maximum load equal to fracture load is 21.054 kN. The total strain at this load is 1.25mm. Find: (a) the ultimate stress, (b) the percentage elongation, (c) the secant modulus if the strain at a stress of 34.474 Mpa is 0.0002mm per mm, and (d) the modulus of toughness assuming that the stress-strain curve is parabolic.

Solution

a) The ultimate stress is

$$\sigma_u = \frac{P_u}{A_o} = \frac{21.054 \times 10^3}{113.1} = 186.158 \text{ N/mm}^2$$

$$= 186.158 \text{ MPa}$$

b) Percentage elongation

$$D_e = \frac{L_f - L_o}{L_o} 100 = \frac{1.25}{50} \times 100 = 2.54\%$$

c) Secant modulus

$$E = \frac{\sigma}{\varepsilon} = \frac{34.476 \times 10^6}{0.0002} = 172.4 \times \text{GPa}$$

d) Assuming that the stress-strain curve is parabolic, the modulus of toughness, or the area under the stress-strain curve to fracture, becomes

$$T_b = \frac{2}{3}\sigma_u \varepsilon_f = \frac{2}{3} (186.158 \times 0.0254 = 3.152 \text{ N.mm per cu.mm}$$

The compression test

Engineering materials may be divided into two general class according to their manner of failure in compression. These are:

a. Ductile (plastic or viscous) materials: which include those which will flow without showing any other indication of failure. E.g. Wrought iron and soft steel.

b. Brittle materials: which include those which will crush to a powder, or crumble to pieces, or fail by shearing on definite angles under compressive load. E.g. Cast iron, concrete, brick and stone.

Nominal stress strain properties in compression

The stress strain properties defined for tension can also be defined for brittle materials under compression. However the mechanical properties for ductile materials in the plastic range can not be determined.

Excercise-3

A concrete cylinder 150 mm in diameter with a gage length of 250 mm used to obtain a stress-strain curve in compression, failed at a load of 249.8 kN and a total strain of 0.472 mm. Determine: (a) the ultimate and fracture strengths, (b) the percentage contraction at fracture, (c) the modulus of toughness, assuming a parabolic stress-strain curve, and (d) the secant modulus for a stress of 4.5 MPa and a total strain of 0.091 mm.

Solution

The cross-sectional area of the specimen is

$$A_o = \frac{\pi(150)^2}{4} = 17,671.5 \text{ mm}^2$$

a) Ultimate and fracture strength

$$\sigma_u = \frac{P_u}{A_o} = \frac{249.8 \times 10^3}{17,671.5} = 14.14 \text{ N/mm}^2$$

$$= 14.14 \text{ MPa}$$

b) Percentage contraction at fracture

$$\frac{\Delta \ell}{\ell_o} 100 = \frac{0.472}{250} 100 = 0.19\%$$

c) The modulus of toughness based on a parabolic stress-strain curve is

$$T_b = \frac{2}{3}\sigma_u \varepsilon_f = \frac{2}{3} \times 14.14 \times \frac{0.472}{250} = 0.018 \text{ mm.N/mm}^3$$

d) The secant modulus at a stress of 4.5 MPa becomes

$$E = \frac{\sigma}{\varepsilon} = \frac{\sigma \ell_o}{\Delta \ell} = \frac{4.5 \times 10^6 \times 250}{0.472} = 2.383 \text{ GPa}$$

The shear test

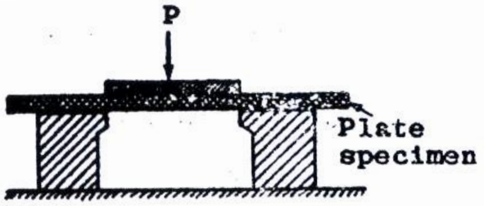
Two types of test are used to determine the property of material in shear. These are:

a. Direct or transverse shear test: encountered in rivets and bolts.

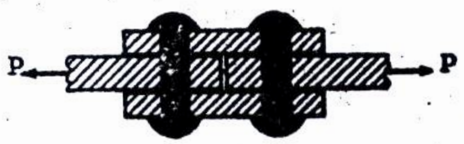
b. Pure or torsional shear test: occurs in shafts subjected to torsion.

Direct or transverse shear tests

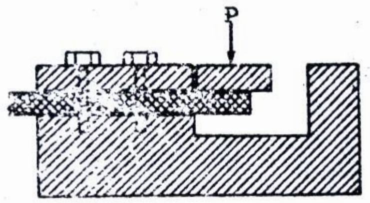
These tests are applied to a specimen by different means such as the Johnson's shear tool. The disadvantage of these types of test is that no strain readings are recorded. The only property obtained is an average value of the ultimate strength in shear, which is equal to the maximum load obtained divided by the shear area.



(a) Punching shear test for plates



(b) Shear test for rivets

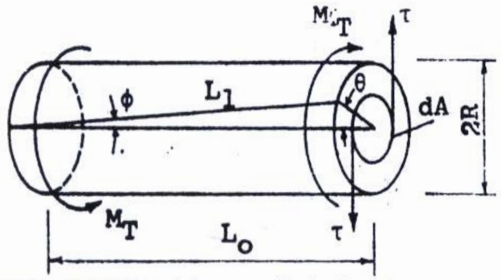


(c) Johson's shear tool for metals

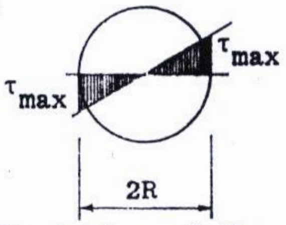
Pure or torsional shear

The advantage of this test is that properties such as the torsional yield strength, the modulus of elasticity in shear can be obtained in addition to the ultimate strength in shear. In this test, a specimen, generally of circular cross-section, is subjected to a twist by a means of torsion testing equipment and the twisting moment and corresponding angle of twist is recorded. From the torque and angle of twist readings, torque-twist diagrams are plotted.

A. Elastic strength:



(a) Application of twisting moment



(b) Variation of the shear stress along the cross-section

The twisting moment is resisted by shear stresses set up in the cross-section of the bar.

$$\boxed{M_T = \frac{\tau J}{r} \quad \text{or} \quad \tau = \frac{M_T\, r}{J}}$$

Where: τ = Shear stress, MPa

M_T = Twisting moment or Torque, N-m

r = Radial distance measured from center of cylinder, m

J = Polar moment of inertia, m^4

For a cylindrical specimen where J= π $D^4/32$, the maximum shear stress is:

$$\boxed{\tau_{max} = \frac{M_T\, D/2}{\pi D^4/32} = \frac{16 M_T}{\pi D^3}}$$

For thin walled tubular specimen, the shear stress on the outer surface is:

$$\boxed{\tau = \frac{16 M_T D_1}{\pi(D_1^4 - D_2^4)}}$$

Where : D_1= outside diameter of the tube

D_2= inside diameter of the tube

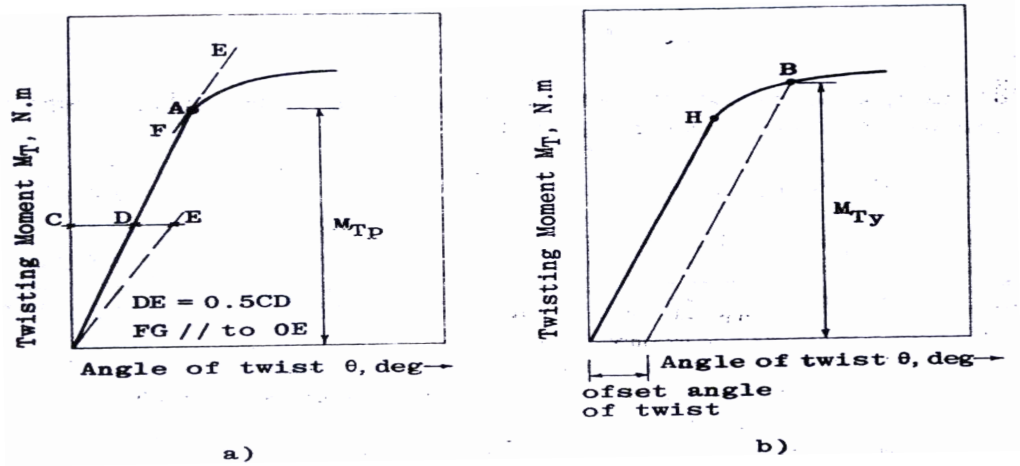


Fig: Torque twist diagram for the elastic range

B. Stiffness:

The constant of proportionality which measures the resistance to torsional deformation or stiffness in torsion, is the modulus of elasticity in shear E_s, sometimes called the modulus of rigidity.

$$\boxed{\begin{array}{l} \tau = E_s \varepsilon_s \\ E_s = \dfrac{M_T L}{\theta J} \end{array}}$$

C. Resilience:

This is represented by the average work per unit volume required to stress the material in torsion to the proportional limit. The average work per unit volume is:

$$\boxed{R_S = \frac{M_p \theta_p}{2} \cdot \frac{1}{A.L}}$$

D. Ductility:

An approximate but more accurate method of defining ductility in torsion is to specify the percentage elongation of an outer fiber, i.e.

$$D_T = \frac{(L_1 - L_o)}{L_o} 100$$

Where: L_o= the original length of the outer fiber

L_1 = The final fracture length of an outer fiber,

E. Toughness:

Toughness in shear is the average work done per unit volume required to fracture a specimen. Toughness or the approximate value of the average work done per unit volume for fracture is:

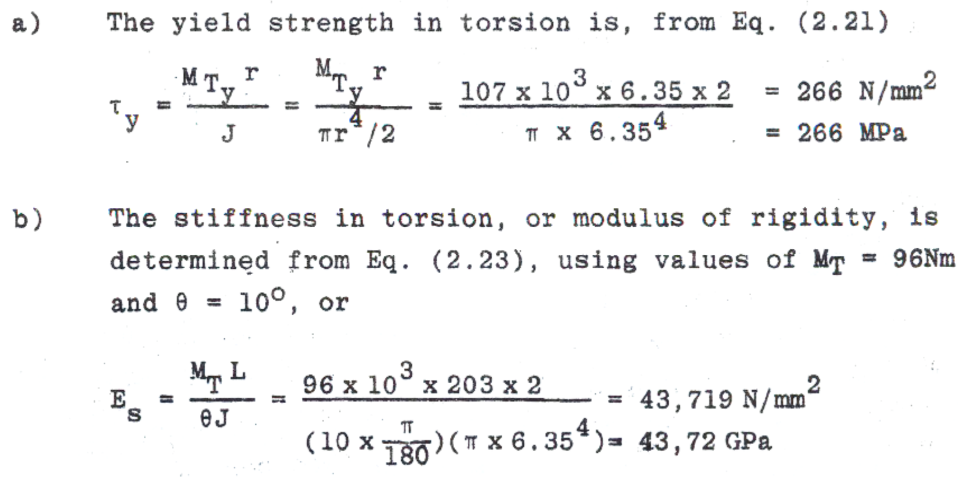
$$T_s = \frac{M_{Tu} \theta_f}{AL}$$

Excercise-3

Stress-strain properties in torsion for a ductile material

In a torsion test of a solid, round brass specimen the yield torque was 107 Nm and maximum torque was 158 Nm. The fracture angle of twist was 515° and, for a torque of 96 Nm on the linear part of the torque-twist diagram, the angle of twist was 10°. A specimen diameter of 12.70 mm and a gage length of 203mm were used. Determine the following torsional shear properties: a) the yield strength, (b) the stiffness or modulus of rigidity, (c) the average modulus of elastic resilience, (d) the apparent ultimate strength or modulus of rupture, and (e) the approximate modulus of toughness.

Solution:

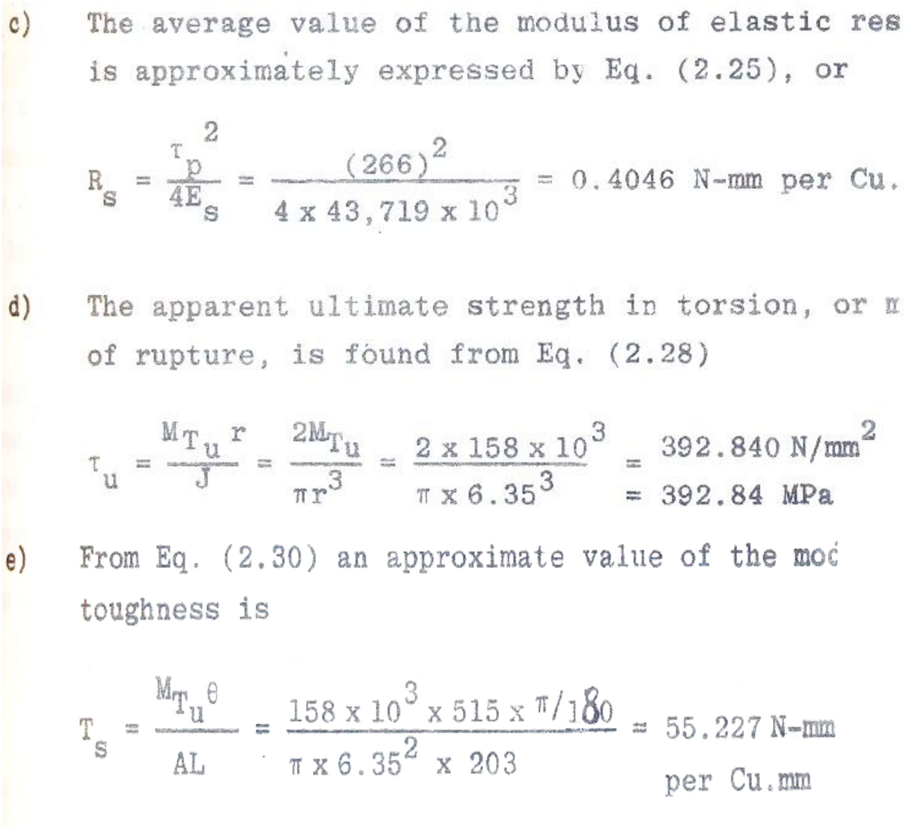


a) The yield strength in torsion is, from Eq. (2.21)

$$\tau_y = \frac{M_{T_y} r}{J} = \frac{M_{T_y} r}{\pi r^4/2} = \frac{107 \times 10^3 \times 6.35 \times 2}{\pi \times 6.35^4} = 266 \text{ N/mm}^2 = 266 \text{ MPa}$$

b) The stiffness in torsion, or modulus of rigidity, is determined from Eq. (2.23), using values of $M_T = 96\text{Nm}$ and $\theta = 10^\circ$, or

$$E_s = \frac{M_T L}{\theta J} = \frac{96 \times 10^3 \times 203 \times 2}{(10 \times \frac{\pi}{180})(\pi \times 6.35^4)} = 43,719 \text{ N/mm}^2 = 43,72 \text{ GPa}$$



c) The average value of the modulus of elastic res is approximately expressed by Eq. (2.25), or

$$R_s = \frac{\tau_p^2}{4E_s} = \frac{(266)^2}{4 \times 43,719 \times 10^3} = 0.4046 \text{ N-mm per Cu.}$$

d) The apparent ultimate strength in torsion, or m of rupture, is found from Eq. (2.28)

$$\tau_u = \frac{M_{T_u} r}{J} = \frac{2M_{T_u}}{\pi r^3} = \frac{2 \times 158 \times 10^3}{\pi \times 6.35^3} = 392.840 \text{ N/mm}^2 = 392.84 \text{ MPa}$$

e) From Eq. (2.30) an approximate value of the moc toughness is

$$T_s = \frac{M_{T_u} \theta}{AL} = \frac{158 \times 10^3 \times 515 \times \pi/180}{\pi \times 6.35^2 \times 203} = 55.227 \text{ N-mm per Cu.mm}$$

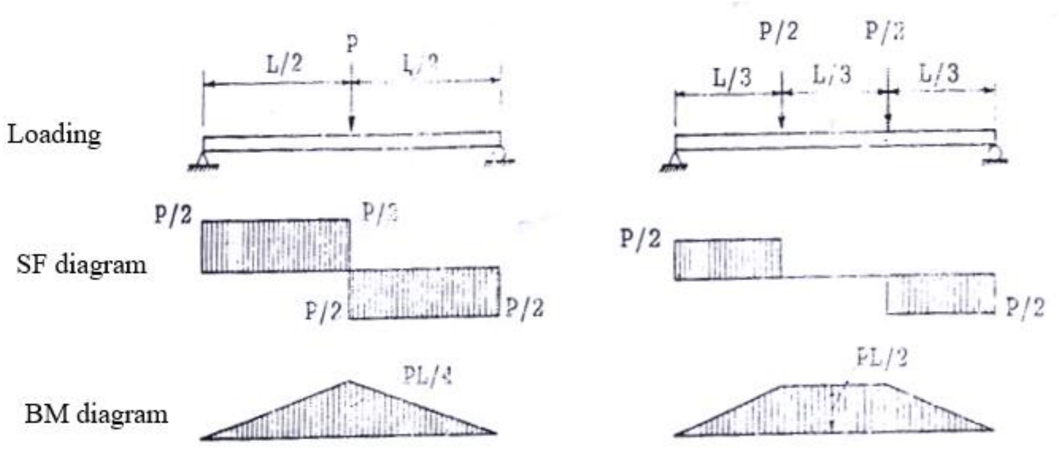
The bending test

Many members in structure are subjected to forces acting transverse to their longitudinal axis. Such members are said to be subjected to bending or flexure. Basically, there are two commonly adopted types of loading in bending test; center point loading and two point loading.

Two point loading is considered a more accurate measure of the bending properties for the following reasons:

a. The maximum moment, hence stress is applied over an appreciable length of the specimen.

b. Bending stresses free from transverse shear stresses are produced for an appreciable length of the specimen.



a) Center-point loading

b) Two-point loading

Loads and deflections are measured to failure at predetermined increments of load which gives a load-deflection diagram. Ductile and brittle materials behave differently under bending.

a) Ductile material

b) Brittle material
Type A

c) Brittle material
Type B

Load-deflection diagram for ductile and brittle materials

Properties for the elastic and plastic range

A. Elastic strength: the elastic strength in bending is determined based on either the proportional-limit load corresponding to Johnson's apparent elastic limit or the yield load using the offset method.

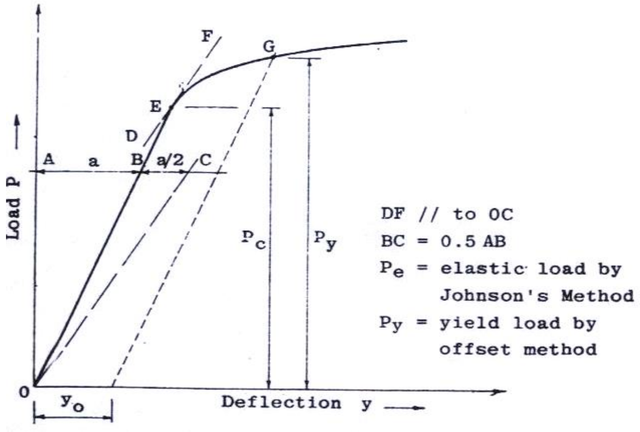


Fig: Determination of elastic and yield loads in bending

The elastic strength, defined as the maximum bending stress in the specimen corresponding to either the proportional limit load P_e or the yield load P_y, is given by:

$\boxed{\sigma_{b_y} = \frac{M_y C}{I}}$ Where:

M_y= Maximum moment in N-m corresponding to the loads Pe or Py (M=PL/4 and PL/6 for center- point and two point loading respectively).

C= Distance in m from the neutral axis to the outer most fiber, and

I= Moment of inertia of the cross-section in m^4.

The type of cross-section influences the elastic bending strength as shown below:

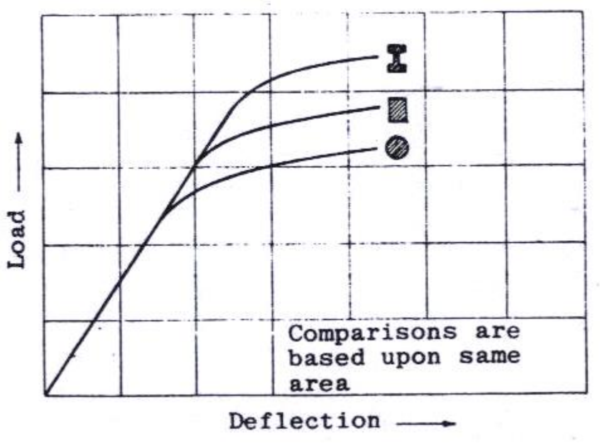


Fig: Influence of cross-section on bending strength

B. Stiffness

The resistance to deformation in bending in the elastic range is called stiffness in bending and is measured by the modulus of elasticity in bending.

From the deflection-load relation and the deflection equation, the maximum deflection is given by:

$$y = k_b \frac{PL^3}{EI}$$

Hence for a point on the straight line portion, with load P and deflection y, the modulus of elasticity in bending will be:

$$\boxed{E_b = k_b \frac{PL^3}{yI}}$$

$K_b = 1/48$ for a beam under center point loading
$K_b = 23/1296$ for a beam under two point loading

C. Resilience:

The resilience in bending is the average work done in stressing a specimen in bending to the proportional limit load P_p. For simply supported beam with a center load the modulus of resilience in bending is given as follow:

$$R_b = \frac{P_p y_p}{2} \cdot \frac{1}{AL}$$

For center point loading we have [$y_p = P_pL^3/48EI$] and [$\sigma_p = M_pC/I = P_pLC/4I$], using the values of y_p and $P_p = 4I\sigma_p/LC$. For a specimen of rectangular cross section of width b and depth d, $I=bd^3/12$, $C=d/2$, $A=bd$, the resilience in the above equation becomes:

$$\boxed{R_b = \frac{\sigma_p^2}{18E}}$$

D. Plastic strength:

The stress obtained is known as the modulus of rupture in bending. Then if M_u is the maximum value of the bending moment, the modulus of rupture in bending is:

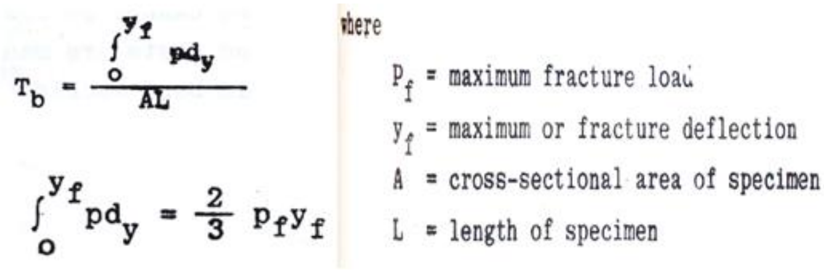
$$\boxed{\sigma_{b_u} = \frac{M_u C}{I}}$$

E. ductility:

For brittle materials fracture in bending, the ductility is measured as the maximum deflection at fracture whereas for ductile materials that cannot be fractured in the usual type of loading, cold bend tests are made using apparatus such as the Olsen cold bend machine.

F. Toughness:

For brittle materials, toughness is measured by the average work done per unit volume to fracture the specimen whereas for some brittle materials the load-deflection curve may be assumed to be parabolic so that



$$T_b = \frac{\int_0^{y_f} p\,d_y}{AL}$$

$$\int_0^{y_f} p\,d_y = \frac{2}{3} p_f y_f$$

where

P_f = maximum fracture load

y_f = maximum or fracture deflection

A = cross-sectional area of specimen

L = length of specimen

Excercise-4

Determination of static bending properties.

A wood specimen 50 by 50 mm in cross-section, with a span length of 510 mm, was tested with a center load to fracture. The proportional limit load was 4,359 N and the maximum fracture load was 4,982 N. For a load of 2,669 N on the linear part of the load deflection diagram the center deflection was 1.524mm. Determine: (a) the proportional limit, (b) the modulus of elasticity in bending, (c) the average elastic resilience per unit volume, and (d) the modulus of rupture.

Solution:

a) The maximum bending stress at the proportional limit is

$$ {}_p = \frac{M_p C}{I} = \frac{(P_p L/4)(d/2)}{(bd^3/12)} = \frac{3P_p L}{2bd^2} $$

$$ = \frac{3 \text{ x } 4359 \text{ x } 510}{2 \text{ x } 50 \text{ x } 50^2} = 26.677 \text{ N/mm}^2 $$

$$ = 26.68 \text{ MPa} $$

b) The modulus of elasticity in bending is

$$ E_b = \frac{PL}{48Iy} = \frac{PL^3}{4bd^3y} $$

$$ = \frac{2669 \text{ x } 510^2}{4 \text{ x } 50 \text{ x } 50^3 \text{ x } 1.52d} = 9{,}293.533 \text{ N/mm}^2 $$

$$ = 9.292 \text{ GPa} $$

c) For a beam of rectangular cross section the average resilience per unit volume is expressed by Eq.2.38, or

$$ R_b = \frac{\sigma_y^2}{18 E} = \frac{26{,}677^2}{18 \text{ x } 9{,}292.533} = 0.00425 \text{ N.mm per cu.mm.} $$

d) The modulus of rupture is

$$ \sigma_u = \frac{3.P_u L}{2bd^2} = \frac{3 \text{ x } 498 \text{ x } 510}{2 \text{ x } 50 \text{ x } 50^2} = 30.490 \text{ N/mm}^2 $$

$$ = 30.49 \text{ MPa} $$

Relationship between material constants

The three material constants, the modulus of elasticity in tension (E), the modulus of elasticity in shear (E_s) and the poisons ratio (μ) are generally used to describe the elastic behaviour of materials and are related by the following equation.

$$\boxed{E_s = \frac{E}{2(1+\mu)}}$$

CHAPTER-2: LIME AND GYPSUM

2.1 LIME

Introduction

In general sense, Cements are materials with adhesive and cohesive properties which make them capable of uniting or bonding together fragments or particles of solid matter into a compact whole. For engineering purpose, the term cement is restricted to those materials when mixed with water form a paste.The paste is temporarily plastic but later it sets and hardens to a rigid mass. Cements of this kind are known as calcareous cement whose principal constituents are compound of lime. Calcareous cements are classified into Non-hydraulic cements and hydraulic cements.

A. Non-Hydraulic cements: are cements which are either not able to set and harden in water (E.g. Non-hydraulic lime) or which are not stable in water (e.g. gypsum plasters).

B. Hydraulic cements: are cements which are able to set and harden in water, and give a solid mass which does not disintegrate, i.e. remain stable in water. E.g. Portland cement.

Lime, gypsum and cement are used in the construction of buildings and engineering works as:

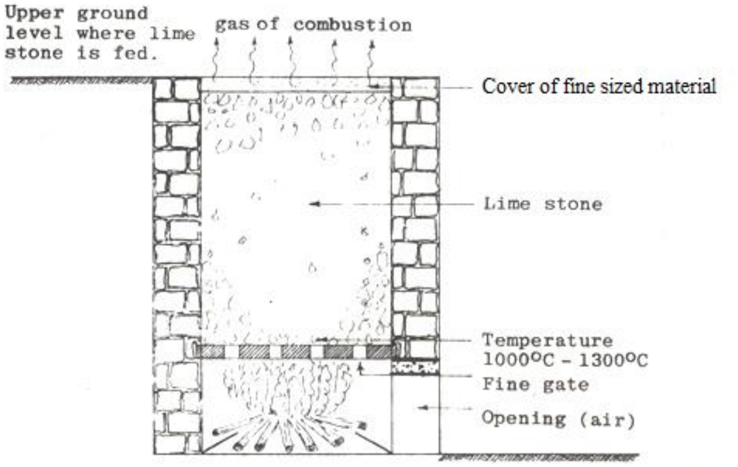
- ✓ Components for binding materials, E.g. Mortar, or
- ✓ Constituents of building materials, E.g. Concrete.

Lime was used throughout the world by the ancient civilizations as a binding agent for brick and stone. It is found in many parts of the world in its natural form as a rock of varying degree of hardness. It is mainly composed of calcium oxide (CaO) which in its pure form associates with CO_2 to give white $CaCO_3$. Lime deposits are found mixed with impurities such as CO_2, Fe_2O_3, $MgCO_3$, etc.

Production of lime

The production of lime involves burning of the raw material and then slaking. The mineral is quarried, crushed, ground, washed and screened to the required size range. The limestone is burnt at approximately 1000-1300°C in either horizontal rotary kilns or vertical shaft kilns which drive off the carbon dioxide to produce quicklime or lump lime (calcium oxide). The amount of heat applied and the method of slaking depend on whether the product is hydraulic or non-hydraulic lime.

$$\underset{\text{calcium carbonate}}{CaCO_3} \longrightarrow \underset{\text{lime}}{CaO} + \underset{\text{carbon dioxide}}{CO_2}$$



Lime kiln

A. Quick lime

The manufacturing of Non-hydraulic lime (Commercial or building lime) consists in burning the limestone at a temperature of 1000°c. The CO_2 is driven off, leaving the CaO which is known as quick lime or caustic lime.

- White in color and have S.G. of about 3.4.
- Highly caustic and possess a great affinity for water.
- It must be kept in dry storage and carefully protected from dampness.

B. Hydrated lime (Slaked lime)

The controlled addition of water to quicklime produces hydrated lime as a dry powder. The mixing of water with quick lime is called slaking or hydration of lime. The addition of water to quicklime – is a highly exothermic reaction. The resulting product is calcium hydroxide ($Ca(OH)_2$) and is called slaked lime or hydrated lime. The hydrated lime is ready to be made into plaster or mortar by adding water and sand to form a temporary plastic mass. There are two types of slaking based on the amount of water add.

I. Wet-slaking: An excess of water is added and the resulting slaked lime is passed through a fine sieve to remove slow slaking particles and then left to mature for several days.

  - ✓ The lime must be continually stirred by a shovel or a stick during the slaking process to reduce unhydrated particles.
  - ✓ Unhydrated particles might hydrate later and cause popping, pitting, and disintegration or expansion of brick work.

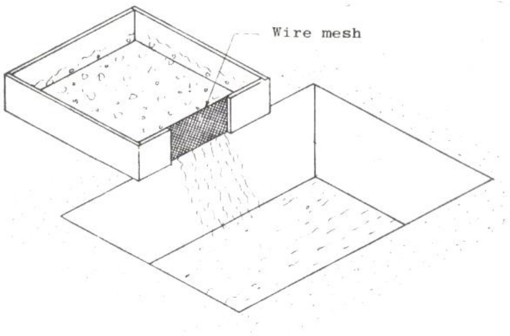
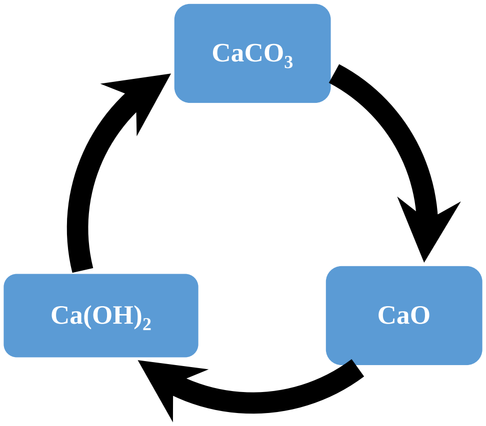


Fig: Arrangement for wet slaking

II. Dry-slaking: It is obtained by adding almost exactly the theoretical quantity of water required to change the burnt lime into hydrated lime. The proportion of lime and water and stirring are scientifically carried out by mechanical means. It is a better product and is of uniform quality because it is manufactured under controlled conditions. Depending on the impurities present; The S.G. of hydrated lime varies from 2.08 to 2.4.

Setting and hardening of lime

Slaked lime hardens or sets by gradually losing its water through evaporation and absorbing CO_2 from the air, thus changing back from $Ca(OH)_2$ to $CaCO_3$. The cycle is completed in the chemical changes from the original limestone, through burning, slaking, and setting as shown below.



The use of lime

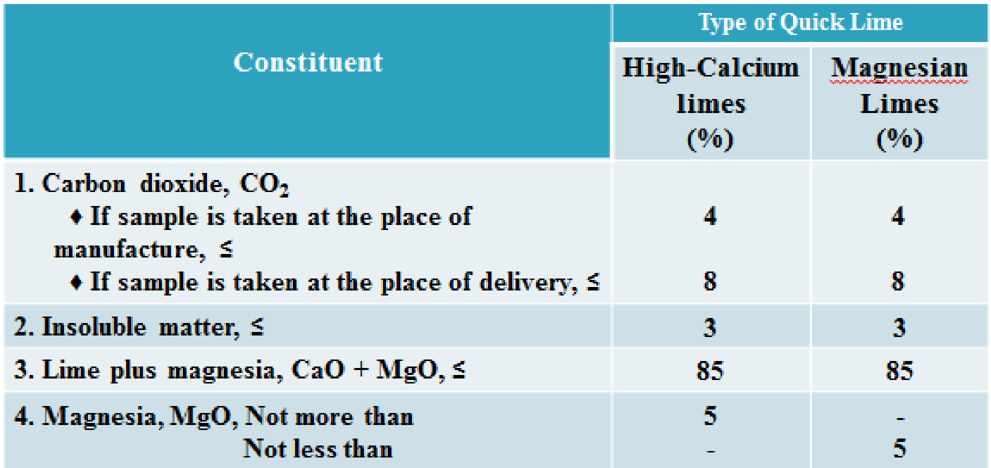
Slaked lime is chiefly used to make mortar for building brick and stone masonry and plastering walls of buildings. When used for the above purpose, quick lime should be completely hydrated by slaking for several days depending upon:

- ✓ Kind of lime,
- ✓ Temperature, and
- ✓ Slaking condition.

In plastering, hard burnt particles left unslaked will absorb water from the atmosphere and become slaked in due course creating pockets on the surface of the wall plaster. As a result the pockets will ultimately peel off from the wall (popping and pitting). If lime is used alone as plaster or mortar unmixed with other materials, wide cracks will occur on account of the shrinkage of lime. Sand is commonly used to mix with the lime to reduce the shrinkage and for economy of the cost. The usual mixtures for mortar are 1 part of lime to 3-6 parts of sand by volume. Lime mortar will not harden under water, and in all cases exposure to air is necessary for prompt setting. Lime mortar without addition of cement should never be used in foundations or where exposed to moisture. Hydrated limes are often added to Portland cement in proportions varying 5-85% of the cement to produce compo-mortar to increase plasticity and workability.

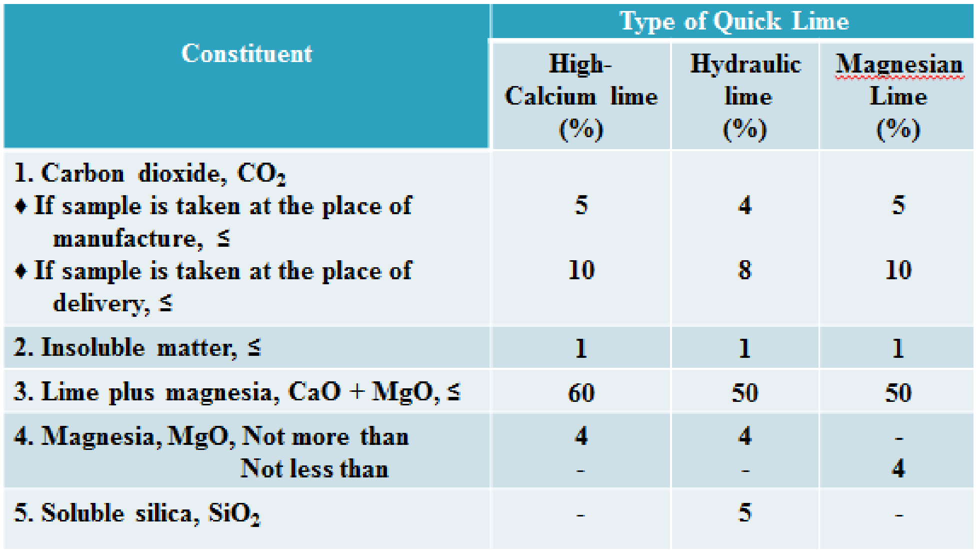
Standards on lime

Chemical requirement for Quick lime (ES.C.D5.002) is shown below:



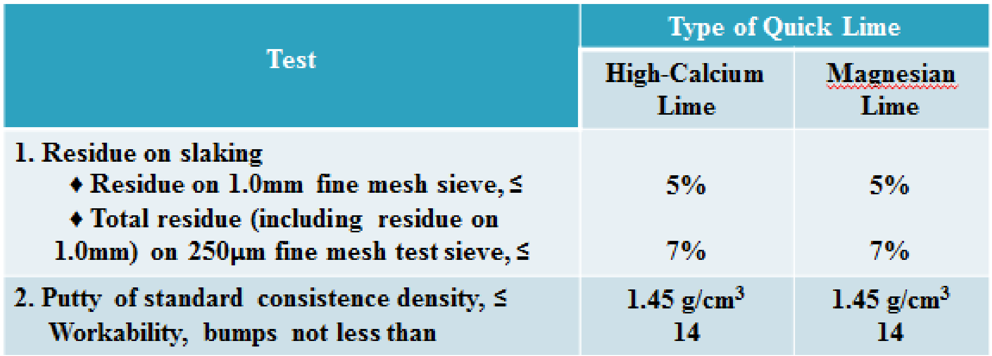
Constituent	Type of Quick Lime	
	High-Calcium limes (%)	Magnesian Limes (%)
1. Carbon dioxide, CO_2		
♦ If sample is taken at the place of manufacture, ≤	4	4
♦ If sample is taken at the place of delivery, ≤	8	8
2. Insoluble matter, ≤	3	3
3. Lime plus magnesia, CaO + MgO, ≤	85	85
4. Magnesia, MgO, Not more than	5	-
Not less than	-	5

Chemical requirement for Hydrated lime (ES.C.D5.003) is shown below:



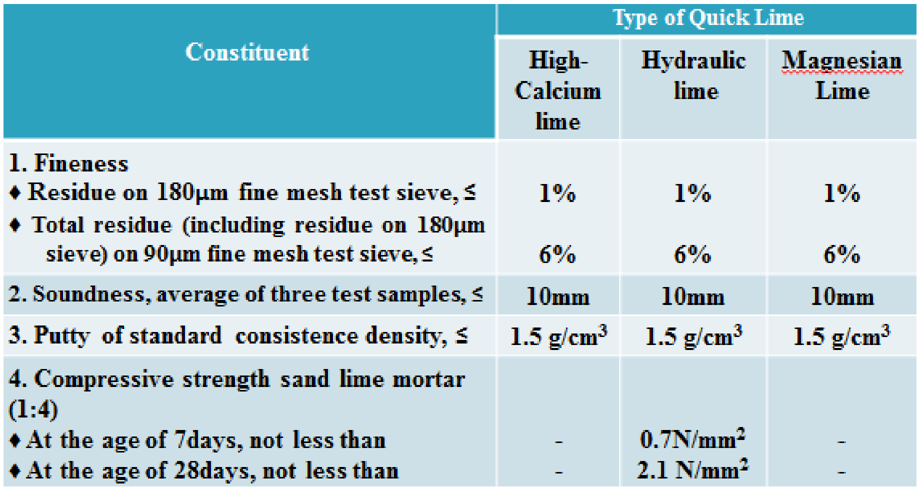
Constituent	Type of Quick Lime		
	High-Calcium lime (%)	Hydraulic lime (%)	Magnesian Lime (%)
1. Carbon dioxide, CO_2			
♦ If sample is taken at the place of manufacture, ≤	5	4	5
♦ If sample is taken at the place of delivery, ≤	10	8	10
2. Insoluble matter, ≤	1	1	1
3. Lime plus magnesia, CaO + MgO, ≤	60	50	50
4. Magnesia, MgO, Not more than	4	4	-
Not less than	-	-	4
5. Soluble silica, SiO_2	-	5	-

Physical requirements for Quick lime (ES.C.D5.002) is shown below:



Test	Type of Quick Lime	
	High-Calcium Lime	Magnesian Lime
1. Residue on slaking		
♦ Residue on 1.0mm fine mesh sieve, ≤	5%	5%
♦ Total residue (including residue on 1.0mm) on 250μm fine mesh test sieve, ≤	7%	7%
2. Putty of standard consistence density, ≤	1.45 g/cm^3	1.45 g/cm^3
Workability, bumps not less than	14	14

Physical requirement for Hydrated lime (ES.C.D5.003) is shown below:



Constituent	Type of Quick Lime		
	High-Calcium lime	Hydraulic lime	Magnesian Lime
1. Fineness			
♦ Residue on 180μm fine mesh test sieve, ≤	1%	1%	1%
♦ Total residue (including residue on 180μm sieve) on 90μm fine mesh test sieve, ≤	6%	6%	6%
2. Soundness, average of three test samples, ≤	10mm	10mm	10mm
3. Putty of standard consistence density, ≤	1.5 g/cm^3	1.5 g/cm^3	1.5 g/cm^3
4. Compressive strength sand lime mortar (1:4)			
♦ At the age of 7days, not less than	-	0.7N/mm^2	-
♦ At the age of 28days, not less than	-	2.1 N/mm^2	-

Testing of limes

Certain tests specified by ES on quick lime and hydrated lime are:

- Determination of residue on slaking
- Preparation of lime putty of standard consistence
- Determination of density
- Determination of workability & compressive strength
- Determination of fineness & soundness

2.2 GYPSUM

Introduction

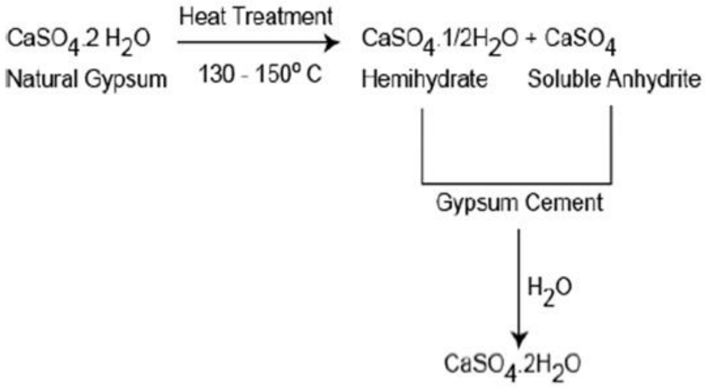
Gypsum plasters are used in the arts and in building construction. Gypsum is a combination of sulphate of lime with water of crystallization. It occurs naturally as either

- Hydrous sulphate of lime ($CaSO_4.2H_2O$) which is generally 76% $CaSO_4$ and 24% H_2O, or Anhydrate ($CaSO_4$)

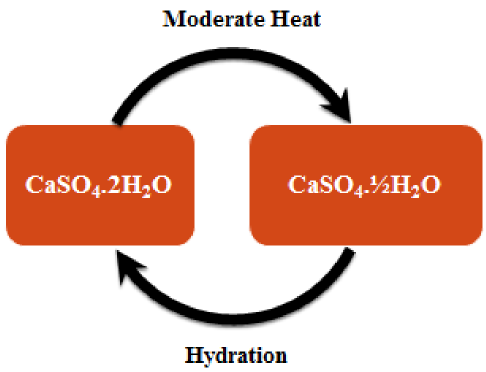
The gypsum rock usually contains silica, alumina, lime carbonate, carbonate of magnesia, iron oxide and other impurities. To be classified as gypsum rock at least 65% by weight must be $CaSO_4.2H_2O$. Pure gypsum is known as alabaster and it is a white translucent crystalline mineral, so soft that it can be scratched with the finger nails. When heated to pure gypsum it loses its lustre and its S.G. is increased from 2.3 to approximately 2.95 due to loss of water.

Manufacture of plasters

A. Plaster of Paris



When mixed with sufficient water to form a plastic paste it sets very rapidly, the whole process taking only 5-10 minutes. The setting of gypsum derivative is not a chemical change as in the setting of carbonate of lime. Re-crystallization takes place.



The setting time of plaster of Paris is delayed by adding a fraction of 1% of a retardant like glue, sawdust, or blood. Plaster of Paris while setting under water, does not gain strength and ultimately, on continued water exposure, will disintegrate. In hardening, plaster of Paris first shrinks and then expands. These property makes the material valuable in making casts. Due to the rapidity of set and difficulty in working its use in structure is limited to ornamental work. It produces hard surface, sharp contours, and is sufficiently strong.

B. Hard-finish plaster

By burning gypsum to a considerably higher temperature there may be produced unhydrous sulphate which is known as unhydrous plaster or high temperature gypsum derivative.

$$CaSO_4.2H_2O + \text{High heat} \longrightarrow CaSO_4 + 2H_2O \uparrow$$

This plaster is less soluble with consequent reluctance to absorb water in the process of recrystallization. The result is a plaster too slow in setting action for practical purposes.

C. Other derivatives of gypsum

I. Gypsum ready-mixed plaster: Which is a calcined gypsum plaster ($CaSO_4.½H_2O$), mixed at a mill with a mineral aggregate, and designed to function as a base to receive various finish coats. It might contain other materials to control setting time and other desirable working properties. The controlled gypsum content is generally 60% or more by weight. Setting time is b/n 1½ and 8 hours. This plaster is less soluble with consequent reluctance to absorb water in the process of recrystallization. The result is a plaster too slow in setting action for practical purposes.

II. Gypsum Neat plaster: Contains not less than 66 weight percent of $CaSO_4.½H_2O$, the remainder being material added at the mill for controlling workability, time of set, and cohesiveness. The addition of aggregate is required on the job.

III. Gypsum wood-fibered plaster: Contains not less than 66 weight percent of $CaSO_4.½H_2O$ and about 1% or more wood fiber to increase cohesiveness and other materials to control workability and time of set.

IV. Gypsum Bond plaster: This is calcined gypsum mixed at the mill with other ingredients to control working quality and setting time and to adapt it for application as a bonding scratch-coat over monolithic concrete. Addition of water only being required on the job. It contains not less than 93 weight percent of calcined gypsum and not less than 2 or more than 5% of hydrated lime.

V. Gypsum Gauging plaster for finish coat: This is prepared for mixing with lime used for the finish coat. It contains not less than 66 weight percent of $CaSO_4.½H_2O$. Materials are added to control setting time and workability.

Standards of gypsum

ASTM specification require that gypsum neat plaster:

- Mixed with 3 parts by weight of standard sand, shall set in not less than 2 hours or more than 16 hours
- When mixed with 2 parts by weight of standard sand its compressive strength not less than $5.2MN/m^2$

ASTM specification require that gypsum wood fibered plaster:

- Shall set in not less than 1½ hours or more than 8 hours
- Shall develop compressive strength not less than $8.3MN/m^2$

CHAPTER 3: MORTAR and CEMENT

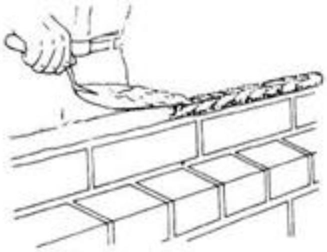
3.1 MORTAR

Definition and use

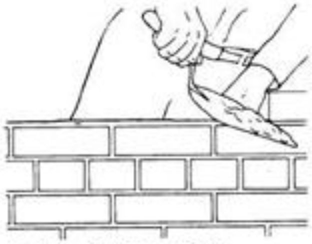
Mortar is the name given to a mixture of sand or similar inert particles with cementing materials and water and has the capacity of hardening into a rock like mass. In general the maximum size of the inert particles in mortar is less than 5mm, and the cementing material is Portland cement and/or lime. In building construction, the uses of mortar are:

a. Jointing medium in masonry construction

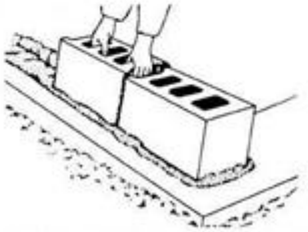
The mortar used to transfer from block to block the pressure that is produced by the weight of the masonry and the super imposed load if any. In such cases the compressive stress on the mortar is as large as on the blocks themselves. The jointing mortar must have satisfactory strength if a durable masonry is to be built.



1. Making a Furrow



2. Cutting Off Excess Mortar



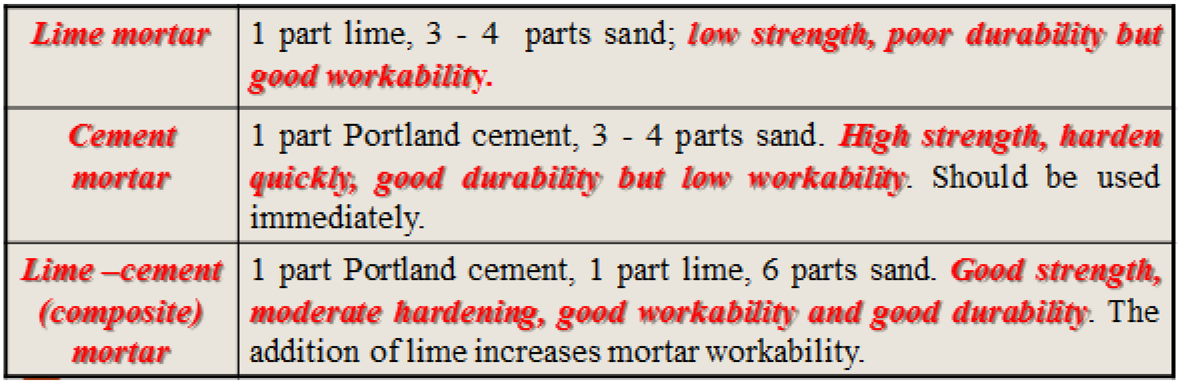
3. POSITIONING AND ALIGNING CORNER BLOCK

b. Wall plaster

Plastering is the process of covering various surfaces of structure with a plastic material such as cement mortar, lime mortar or composite mortar, etc. to obtain an even, smooth, regular, clean and durable surface. Plastering conceals inferior quality materials and defective workmanship and also provides a protective coating against atmospheric effects. It further provides a base for receiving other decorative finishes such as painting and white washing.

Mortar mixes

The traditional mortar material for building work was lime, but later to an increasing extent Portland cement replaced it. While the use of lime results in a relatively workable mixture, rapid development of strength as well as stronger mortar is most conveniently obtained with Portland cement. To combine the advantages compo-mortar is prepared with appropriate proportion of Portland cement, lime and sand.



Lime mortar	1 part lime, 3 - 4 parts sand; ***low strength, poor durability but good workability.***
Cement mortar	1 part Portland cement, 3 - 4 parts sand. ***High strength, harden quickly, good durability but low workability***. Should be used immediately.
Lime –cement (composite) mortar	1 part Portland cement, 1 part lime, 6 parts sand. ***Good strength, moderate hardening, good workability and good durability***. The addition of lime increases mortar workability.

In order to produce a durable mortar of required strength and other essential properties at a minimum cost:

- Careful attention must be given to the selection and proportioning of the component materials.
- The mixture must be workable so that it can be placed and finished without undue labour.
- Since Portland cement is the most expensive ingredient in the mixture, the proportion used should be as small as is consistent with the attainment of desired properties.

The most accurate method of measuring proportions is by weight, however, because of its advantage at the site volumetric proportioning is often used.

Properties of mortar

Workability

Properties of mortars vary greatly because they are dependent on many variables such as:

- The properties of the cementitious materials,
- Ratio of cementitious material to sand,
- Characteristics and grading of sand, and
- Proportion of mixing water.

For the same proportions, lime-sand mortar invariably gives better workability than Portland cement-sand mortar. Mortar produced from sand of circular grains results in better workability than those produced from sand of angular grains. At times admixtures are used in order to improve the workability of cement sand mortar.

Strength

Results of tests on mortars and compo-mortars have shown that strength is affected by a number of factors which include:

- The quality of the ingredients,
- Proportion of the ingredients,
- Water/cement ratio, and
- The curing method and age.

For the same proportions, lime-sand mix gives weaker mortar than cement-sand mix. This is mainly due to two main factors:

- Difference in strength b/n Portland cement and lime pastes. For the same proportions cement gives invariably stronger paste than lime.

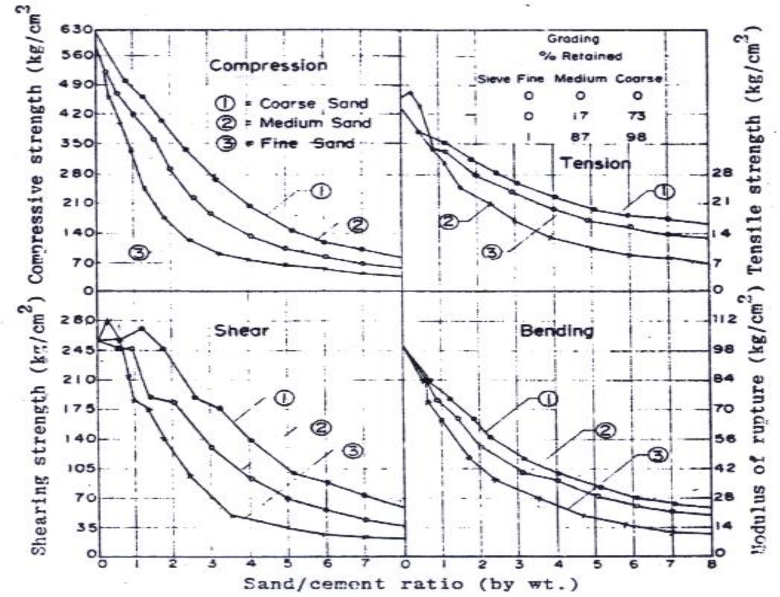
- Portland cement is a better cementing material than lime giving a better bond b/n the paste and the inert material.

The compressive, tensile, shear and bending strengths of cement mortar increases with an increase in the cement content.

- This is true irrespective of the grain size distribution of the sand.
- However, drying shrinkage increases and the mortar becomes prone to shrinkage cracks.

The strength as well as the density of mortars made of the same class of sand decrease as the proportion of fine grains in the sand increases.

Increasing the percentage of mixing water beyond that required to form a placeable mix lowers the strength and density of mortar. And this effect is greatest at early age. The strength of mortar increases with age. The rate of increase is highest at early age and becomes negligible after a year or so. Strength of Portland cement mortars of different proportions made from fine, medium and coarse sand



Water tightness

At times mortar is used in parts of buildings exposed to dampness or moisture and might be required to be water tight. In such case Portland cement should be used because of its hydraulic property and the mix should be rich and dense. Such mortar can be produced by using higher amount of cement, lower water cement ratio and coarse grained size. With the cement content, materials and workability all constant, strength and degree of water tightness increases with the density of the mix.

Materials for mortar: Cementitious ingredients

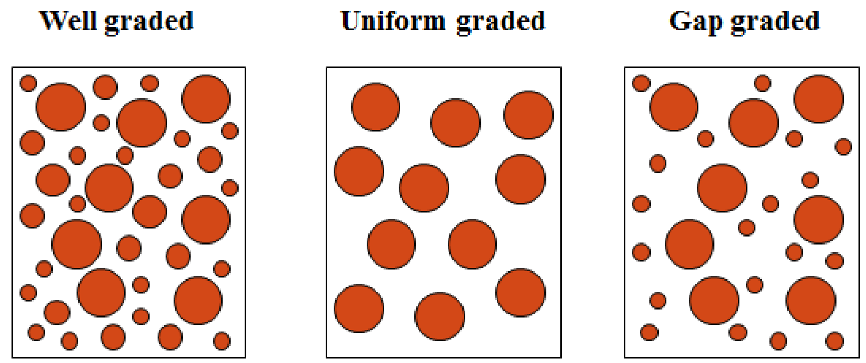
Cement: used for preparing masonry mortars may be:

- Ordinary Portland cement
- Rapid hardening cement
- Blast furnace slag cement
- Portland Pozzolana cement
- Masonry cement

Lime: If lime mortar is used, lime may be of hydraulic or semi hydraulic category. Prepared lime mortar shall be kept damp and shall never be allowed to go dry. Partly set or dried mortar shall never be retempered for use.

Sand: used for making mortar should be well graded, that the particles should not all be fine nor all coarse. If the sand is well graded; The finer particles help to occupy the space (voids) b/n the larger particles and a dense mortar which permits the most economical use of cement and/or lime can be obtained. Sand should be clean, free from dust, loam, clay, and vegetable matter. These foreign particles are objectionable because they:

- Prevent adhesion,
- Reduce strength, and
- Increase porosity.



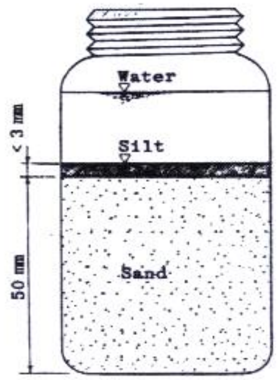
The range of size are approximately in equal amounts

Most particles are of the same size

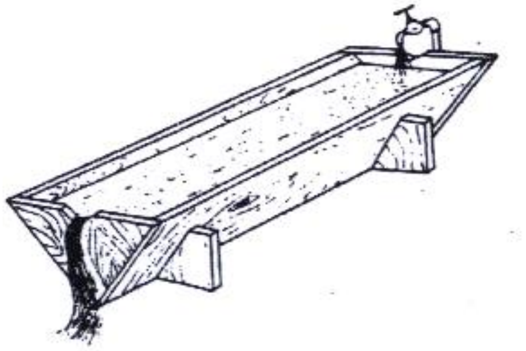
Most particles are of large or small size

Silt test should be made at the site to determine the silt content of the sand. If the silt content is more than 6%, the sand is unsuitable for mortar work unless the excess silt is removed by washing. In order to check the amount of organic matter, colour test could be made as described in ASTM C40.

Water: for mortar mix should be clean and free from industrial wastes.



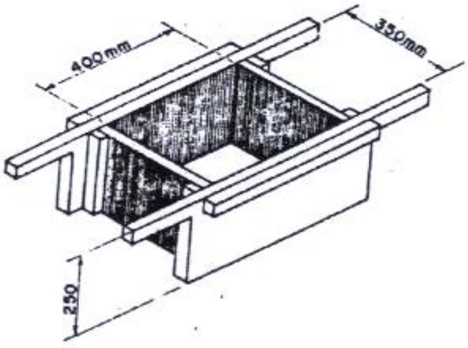
Silt test at construction site



Trough for washing sand

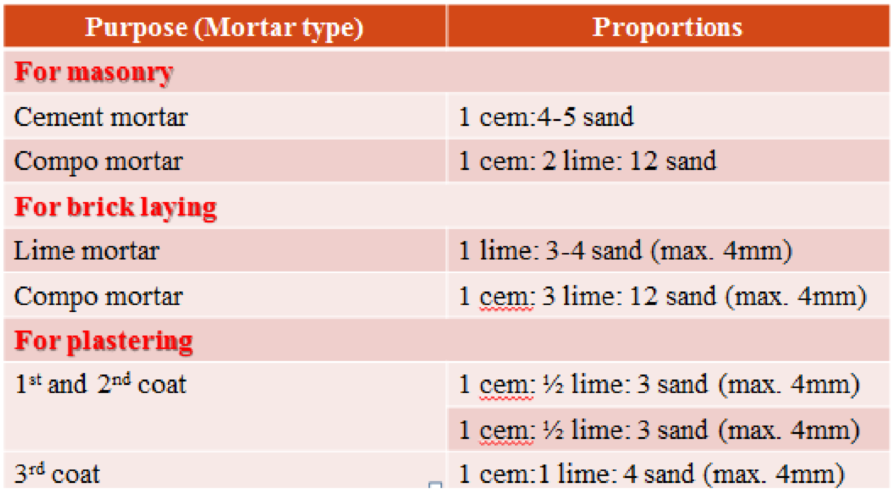
Batching and mixing

Material used for making mortar should be accurately measured, especially when preparing mortar for wall plaster. Cement is usually measured by weight in cement bags whereas wet slaked lime and sand are measured by volume. Each cement bag contains a net weight of 50Kg which corresponds to about 35 litre loose volume. For convenience the other material can be measured using a measuring box made to hold quantities in multiples of 35 litre.



Care should be taken so as to have the sand surface dry. Mortar is usually mixed at the site, and mixing may be by hand or mechanical mixer. Hand mixing must be done on a proper mixing board which should be water tight and clean. A mortar containing cement should be thoroughly mixed in a dry state first and then water added before final mixing. All cement and cement-lime mortars should be used with in the first 2 hours of mixing.

A range of cement-lime-sand mixes in the proportions of 1:½:4½, 1:1:6, 1:3:12 by volume will meet more requirements.



Purpose (Mortar type)	Proportions
For masonry	
Cement mortar	1 cem:4-5 sand
Compo mortar	1 cem: 2 lime: 12 sand
For brick laying	
Lime mortar	1 lime: 3-4 sand (max. 4mm)
Compo mortar	1 cem: 3 lime: 12 sand (max. 4mm)
For plastering	
1st and 2nd coat	1 cem: ½ lime: 3 sand (max. 4mm)
	1 cem: ½ lime: 3 sand (max. 4mm)
3rd coat	1 cem:1 lime: 4 sand (max. 4mm)

Mortar proportions by volume for different purposes

3.2 CEMENTING MATERIALS: “CEMENT”

Introduction

What is cement? A finely ground inorganic material which has cohesive & adhesive properties; able to bind two or more materials together into a solid mass. Cohesion is the tendency of a material to maintain its integrity without separating or rupturing within itself when subject to external forces. Adhesion is the tendency of a material to bond to another material.

Cement when mixed with water form a paste which sets and harden by means of hydration reactions, and which after hardening retain its strength and stability even under water.

Group of cement

Generally cementing materials are of two types:

A. **Non-hydraulic cements**: are cements which are either not able to set and harden in water (E.g. Non-hydraulic lime) or which are not stable in water (e.g. gypsum plasters).

B. **Hydraulic cements:** are cements which are able to set and harden in water, and give a solid mass which does not disintegrate, i.e. remain stable in water. E.g. Portland cement.

History of cement

The history of cementing material is as old as the history of engineering construction. Ancient Egyptian (about 5000 years ago) used calcined impure gypsum. The Greeks (about 1000BC-100BC) and the Romans (about 300BC-300AD) used calcined limestone. The Romans ground together lime and volcanic ash or finely ground burnt clay tiles. The active silica and alumina in the ash and the tiles combined with the lime to produce what became known as Pozzolanic cement from the name of the village Pozzuoli, in Italy. The Romans added blood, milk, and lard to their mortar and concrete to achieve better workability.

Early History of modern cement

John Smeaton (1756) found that the best mortar was found when Pozzolana was mixed with limestone containing a high proportion of clayey matter.

Joseph Aspedin (1824) patented Portland cement. This cement was prepared by heating a mixture of finely divided clay and hard limestone in a furnace until carbon dioxide is driven off.

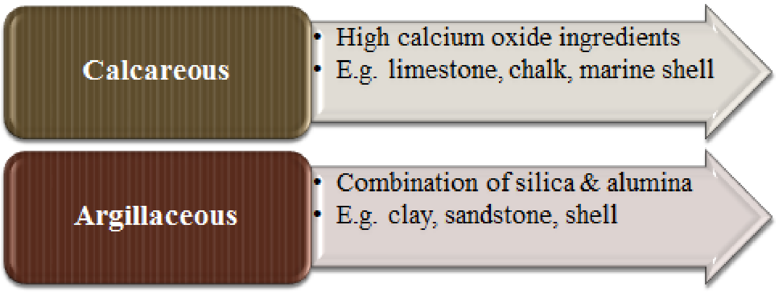
The cement was named after the natural limestone quarried on the Isle of Portland in the English Channel. Later in 1845 Issac Charles Johnson burnt a mixture of clay and chalk till the clinkering stage to make a better cement and established factories in 1851.

The first cement factory was established in Ethiopia in 1936 by the Italians at the Eastern part of the country, Dire Dawa.

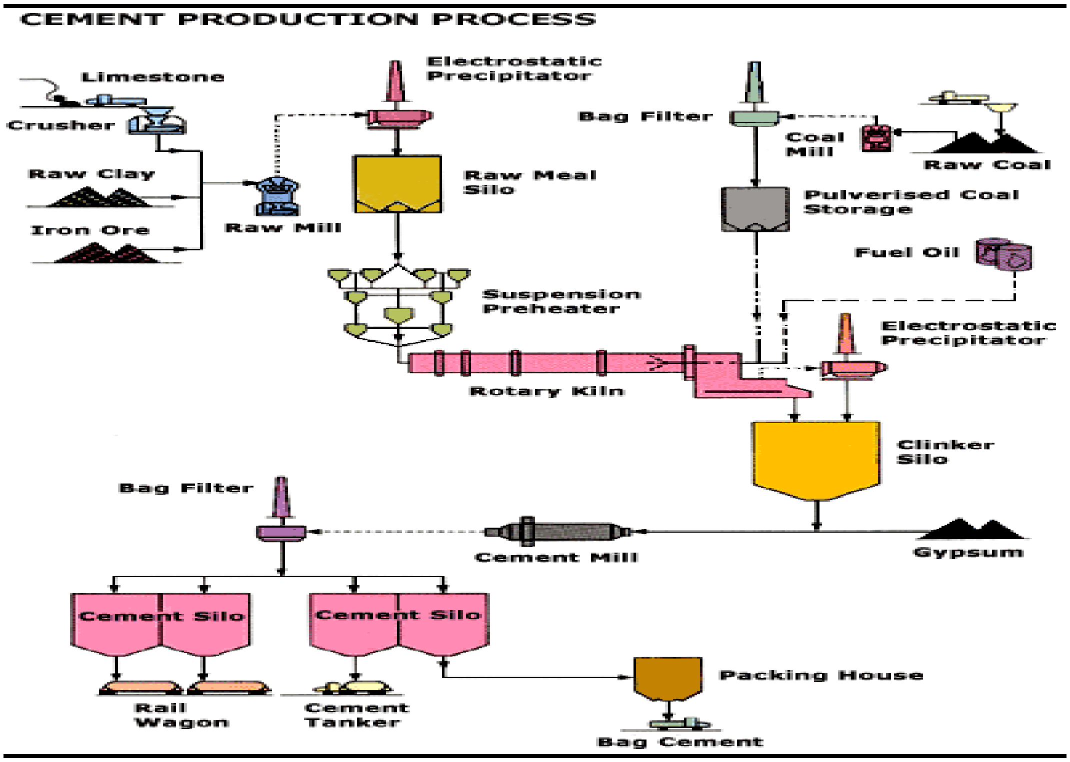
Production of Portland cement

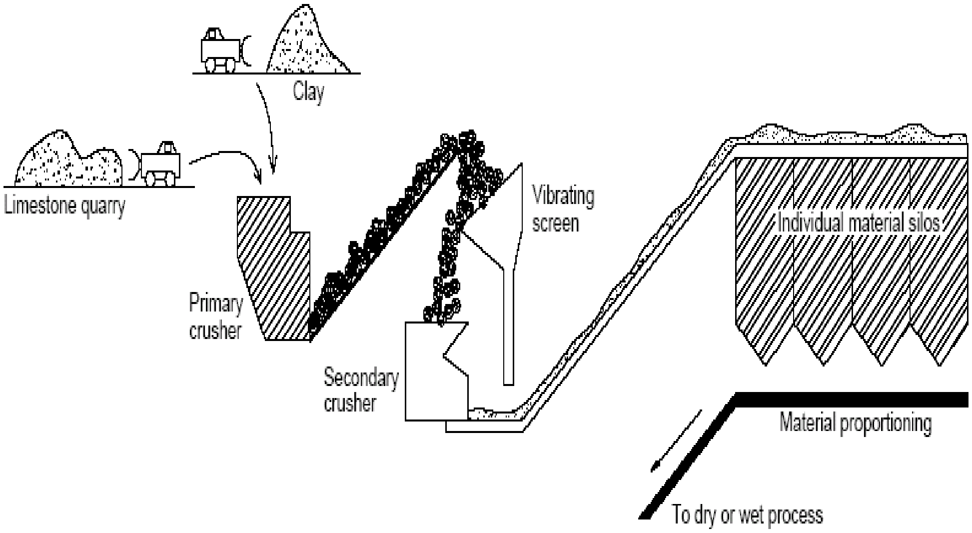
Definition of Portland cement as per ES

Portland cement is a cementing material which is obtained by thoroughly mixing together calcareous or other lime bearing material with, if required, argillaceous and/or other silica, alumina or iron oxide bearing materials burning them at a clinkering temperature and grinding the resulting clinker.



The process of manufacture consists essentially of:


CEMENT PRODUCTION PROCESS
Limestone
Crusher
Raw Clay
Iron Ore
Raw Mill
Electrostatic Precipitator
Raw Meal Silo
Suspension Preheater
Rotary Kiln
Bag Filter
Coal Mill
Raw Coal
Pulverised Coal Storage
Fuel Oil
Electrostatic Precipitator
Clinker Silo
Bag Filter
Cement Mill
Gypsum
Cement Silo
Cement Silo
Packing House
Rail Wagon
Cement Tanker
Bag Cement


Clay
Limestone quarry
Primary crusher
Vibrating screen
Secondary crusher
Individual material silos
Material proportioning
To dry or wet process

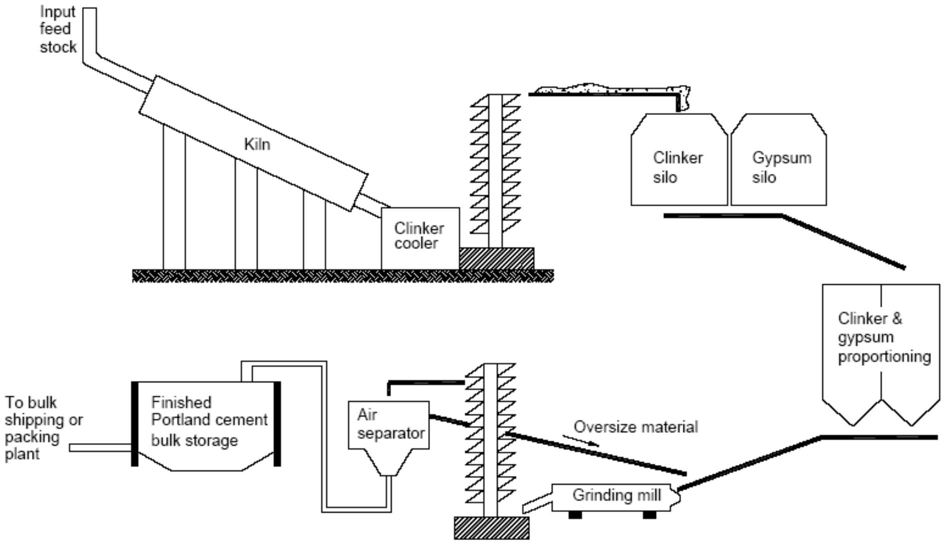


Fig: Cement Factory

Fig: Proportioning of the raw materials

In the manufacture of Portland cement, correct proportioning of the raw materials is of prime importance in securing clinker of proper constitution. In order to fix the proportions accurately, chemical analysis should be made on the raw materials. The results of chemical analysis are usually reported in terms of the oxides of the principal constituent elements.

N.B.

- Cements with lower lime content are slow to harden.
- The presence of free lime in cement may cause volume instability in the hardened cement.
- Alumina and iron oxide acts as a flux to reduce the burning temperature. And the rapidity of the setting of the cement is controlled by these oxides.
- Iron oxides impart the grey colour to cement.

limestone pre-homogenization pile

a completed limestone pre-homogenization pile

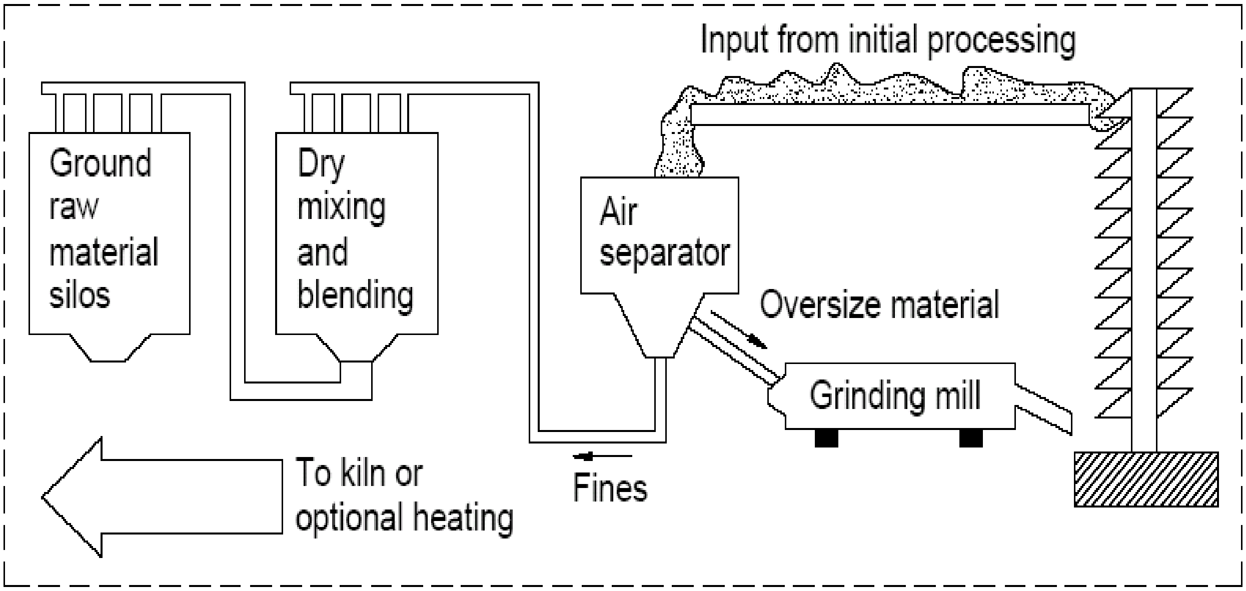
Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O
Limestone	2.68	0.62	0.46	51.85	1.94	0.03	0.05	0.02
Sandy clay	81.56	11.29	1.79	0.12	0.09	0.05	0.14	0.03
Clay	65.18	21.91	3.36	0.11	0.08	0.06	0.19	0.04
Iron ore	14.88	16.79	57.74	0.12	0.56	0.04	0.04	0.03
Shale	61.10	16.42	7.01	1.02	2.34	0.01	4.12	1.65
Sand	94.70	2.90	0.24	0.35	0.13	0.01	0.60	0.21
Bauxite	3.11	57.59	15.74	4.16	0.16	0.29	0.08	0.08
Gypsum	4.31	0.34	0.14	31.19	0.11	43.88	-	-
Fuel Ash	57.20	17.36	9.11	3.95	1.80	3.40	0.78	2.50

Table: Typical composition of some raw materials

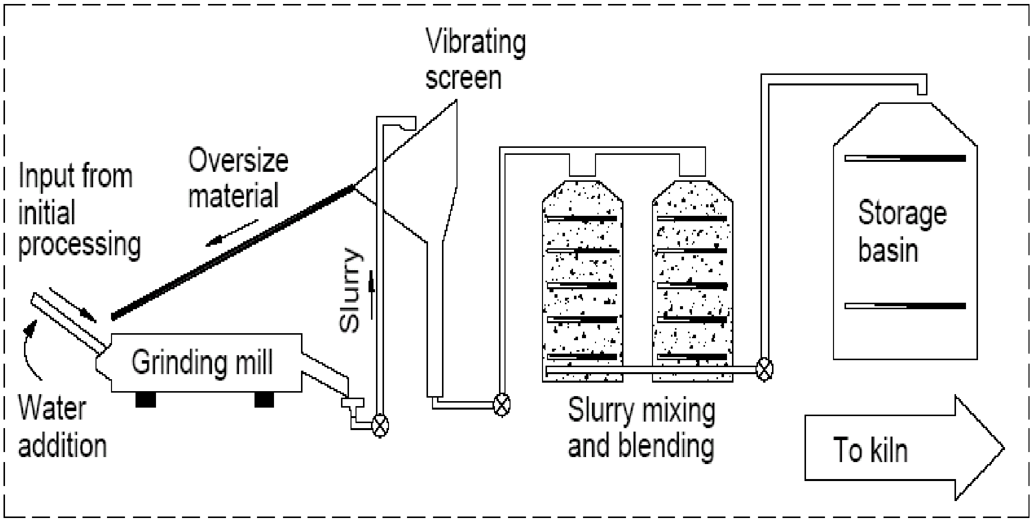
Types of process

There are two process known as “wet” and “dry” process depending upon whether the mixing and grinding of raw materials is done in wet or dry condition.

i. Dry process: In the dry process the raw materials are crushed, dried in rotary driers, proportioned, and then ground in ball mills. The resulting powder is then burnt in its dry condition in the rotary kiln. The difficulty in the control of dry mixing and blending have made this method of production of Portland cement much less popular than the wet process. The dry process requires much less fuel as the materials are already in a dry state. The dry process is shown below:



ii. Wet process: In the wet process the materials are first crushed and then ground and dispersed in water to form a slurry in a wash mill. This process is done for the combined calcareous and argillaceous materials or for each constituent separately which are then mixed in predetermined proportion. The resulting cement slurry with a water content of 35-50% is made to pass through screens to a storage tanks where it is continuously agitated to prevent sedimentation. For many years the wet process remained popular because of the possibility of more accurate control in the mixing of raw materials. The vertical shaft technology employed by mini cement units, use the wet process where as the rotary kiln technology uses the modern dry process. The wet process is shown below:



Burning the mixture in the kiln

The rotary kiln is an important component of a cement factory. It is a thick steel cylinder of diameter 3-8 meters and length sometimes reaching 200m. It is lined with refractory materials and rotates slowly on its axis which is slightly inclined. At the lower end fire is blown in by an air blast. The fuel is either powered coal, oil or natural gas. As the slurry moves downward in the kiln, it encounters a progressively increasing temperature and undergoes a number of chemical changes.

At 100°C – water is driven off

At 850°C – limestone changes to calcium oxide and carbon dioxide (CO_2) is given off.

Upon reaching the hottest part, where the temperature reaches 1400-1500°c the material sinters becoming 20-30% liquid.

At this temperature lime, silica and alumina recombine to form new chemical compounds which fuses into balls, 10-25mm in diameter, which is called clinker.

At the lower end of the kiln the cement clinker then drops into coolers.

Fig: Clinker production

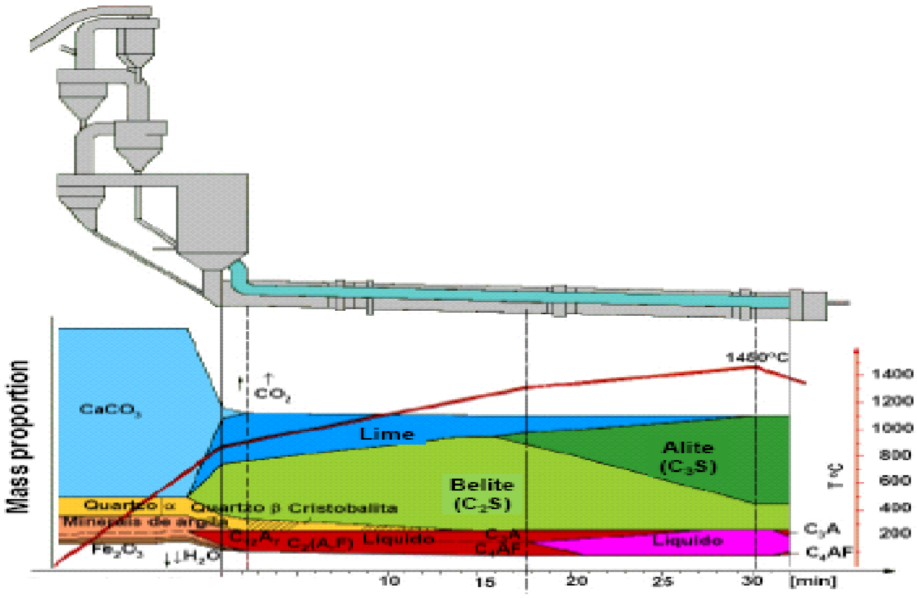
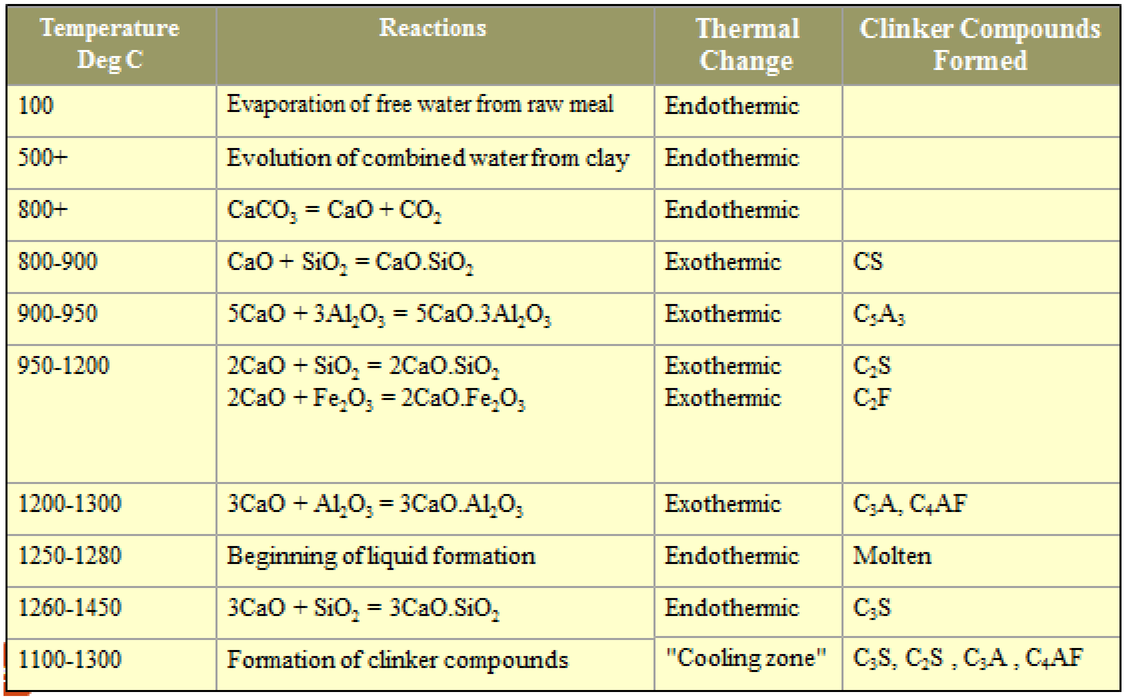


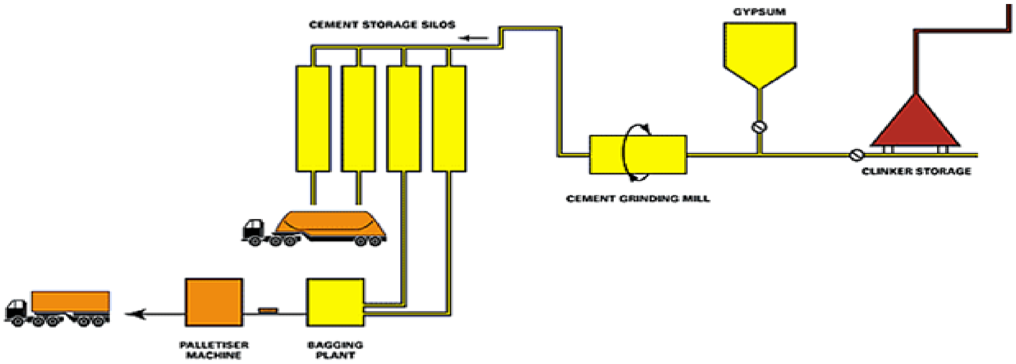
Fig: Reaction in the kiln



Temperature Deg C	Reactions	Thermal Change	Clinker Compounds Formed
100	Evaporation of free water from raw meal	Endothermic	
500+	Evolution of combined water from clay	Endothermic	
800+	$CaCO_3 = CaO + CO_2$	Endothermic	
800-900	$CaO + SiO_2 = CaO.SiO_2$	Exothermic	CS
900-950	$5CaO + 3Al_2O_3 = 5CaO.3Al_2O_3$	Exothermic	C_5A_3
950-1200	$2CaO + SiO_2 = 2CaO.SiO_2$ $2CaO + Fe_2O_3 = 2CaO.Fe_2O_3$	Exothermic Exothermic	C_2S C_2F
1200-1300	$3CaO + Al_2O_3 = 3CaO.Al_2O_3$	Exothermic	C_3A, C_4AF
1250-1280	Beginning of liquid formation	Endothermic	Molten
1260-1450	$3CaO + SiO_2 = 3CaO.SiO_2$	Endothermic	C_3S
1100-1300	Formation of clinker compounds	"Cooling zone"	C_3S, C_2S , C_3A , C_4AF

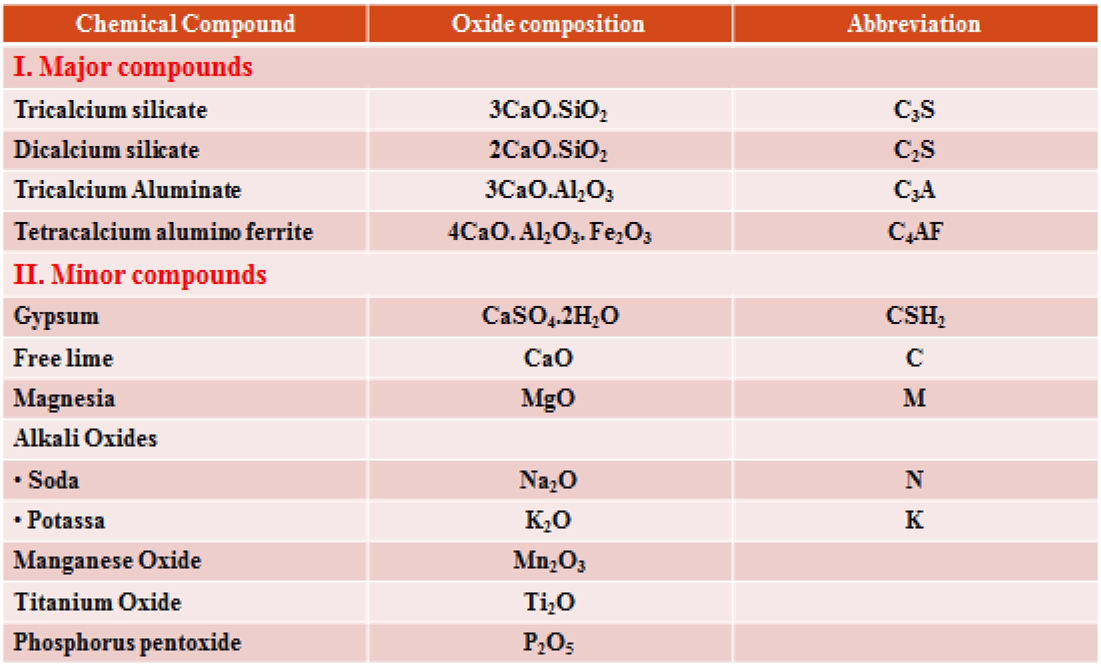
Cooling, grinding and packing

The cool clinker which is characteristically black, glistering, hard and porous is then fed into ball mills where it is inter ground with 5% of gypsum. Once the desired degree of fineness is reached, to about 1 billion particles per gram, the cement is conveyed to storage silos. From the silos it is packed to 50Kg bags or fed directly to bulk cement lories.



Mineral composition of Portland cement: Compound composition of Portland cement

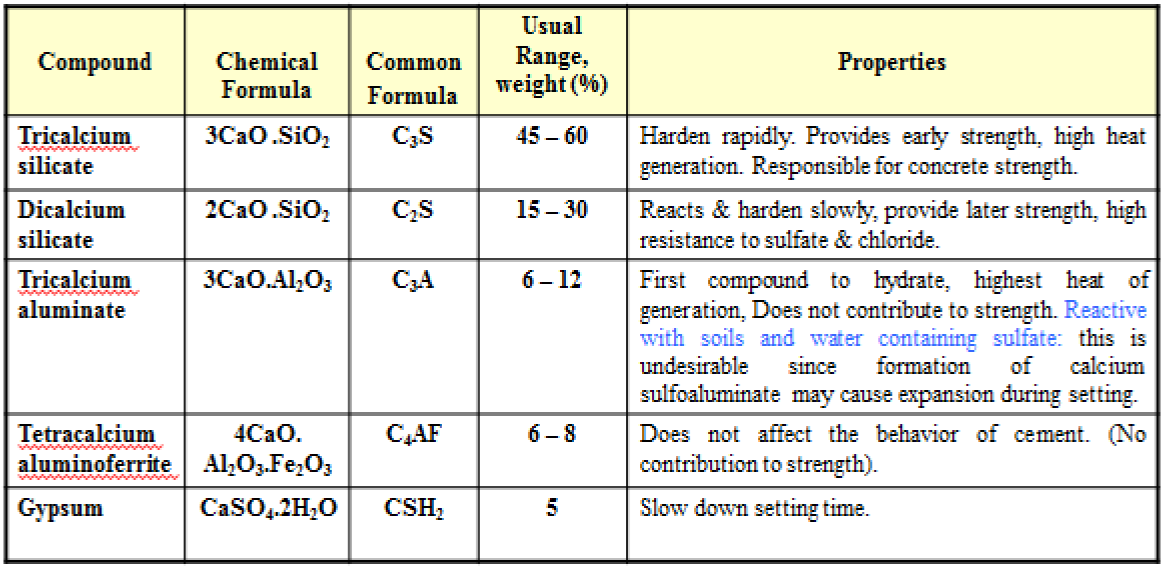
The raw materials used for the manufacture of cement consists mainly of lime, silica, alumina and iron oxide. These oxides interact with one another in the kiln at high temperature to form more complex compounds. The maximum amount of alumina and iron oxide is determined by the need to control the rapidity of the setting of cement. The silicate phases form about 70% of the weight of an ordinary Portland cement. Despite their small percentages, the minor compounds can have strong influence on the properties of fresh and hardened cement paste. Gypsum is added to clinker in the last stage in order to regulate the setting time of cement. The amount of gypsum added depends on the C_3A content of the cement and its fineness.



Chemical Compound	Oxide composition	Abbreviation
I. Major compounds		
Tricalcium silicate	$3CaO.SiO_2$	C_3S
Dicalcium silicate	$2CaO.SiO_2$	C_2S
Tricalcium Aluminate	$3CaO.Al_2O_3$	C_3A
Tetracalcium alumino ferrite	$4CaO. Al_2O_3. Fe_2O_3$	C_4AF
II. Minor compounds		
Gypsum	$CaSO_4.2H_2O$	CSH_2
Free lime	CaO	C
Magnesia	MgO	M
Alkali Oxides		
• Soda	Na_2O	N
• Potassa	K_2O	K
Manganese Oxide	Mn_2O_3	
Titanium Oxide	Ti_2O	
Phosphorus pentoxide	P_2O_5	

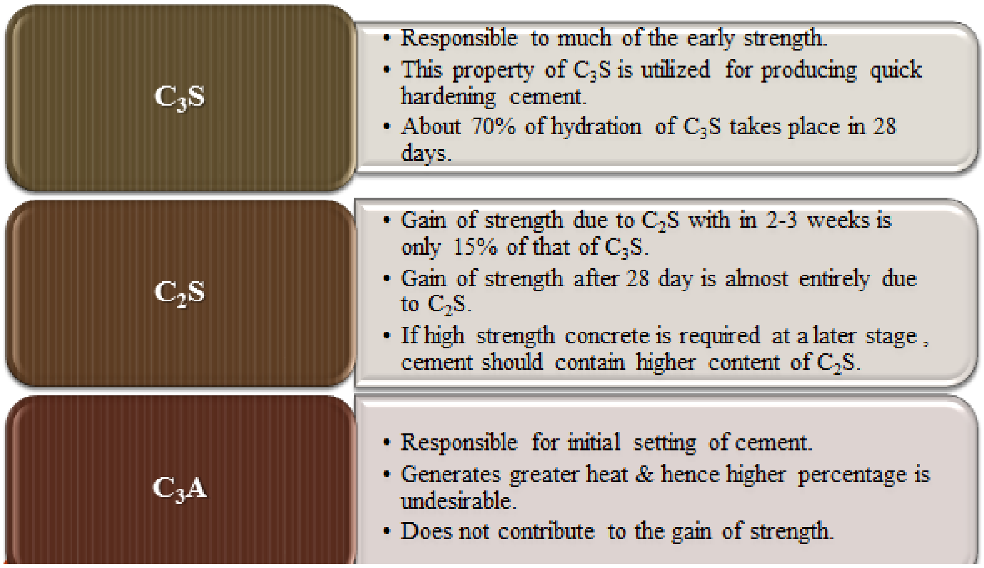
The gypsum content must be limited b/c an excess may cause deterioration in the cement due to the expansive nature of hydrating gypsum. Free lime may present in cement due to the raw material containing more lime than can combine with the acidic oxides such as SiO_2, Al_2O_3, Fe_2O_3 and insufficient burning at the clinkering stage.

Free lime in cement is undesirable since after being hard burnt it is very slow to hydrate when cement is mixed with water. The presence of free lime in cement may cause volume instability in the hardened cement. Magnesia which has a similar hydration to CaO, may cause unsoundness if it is present greater than the upper limit.



Compound	Chemical Formula	Common Formula	Usual Range, weight (%)	Properties
Tricalcium silicate	$3CaO.SiO_2$	C_3S	45 – 60	Harden rapidly. Provides early strength, high heat generation. Responsible for concrete strength.
Dicalcium silicate	$2CaO.SiO_2$	C_2S	15 – 30	Reacts & harden slowly, provide later strength, high resistance to sulfate & chloride.
Tricalcium aluminate	$3CaO.Al_2O_3$	C_3A	6 – 12	First compound to hydrate, highest heat of generation, Does not contribute to strength. Reactive with soils and water containing sulfate: this is undesirable since formation of calcium sulfoaluminate may cause expansion during setting.
Tetracalcium aluminoferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF	6 – 8	Does not affect the behavior of cement. (No contribution to strength).
Gypsum	$CaSO_4.2H_2O$	CSH_2	5	Slow down setting time.

Tips on the major compounds



C_3S

- Responsible to much of the early strength.
- This property of C_3S is utilized for producing quick hardening cement.
- About 70% of hydration of C_3S takes place in 28 days.

C_2S

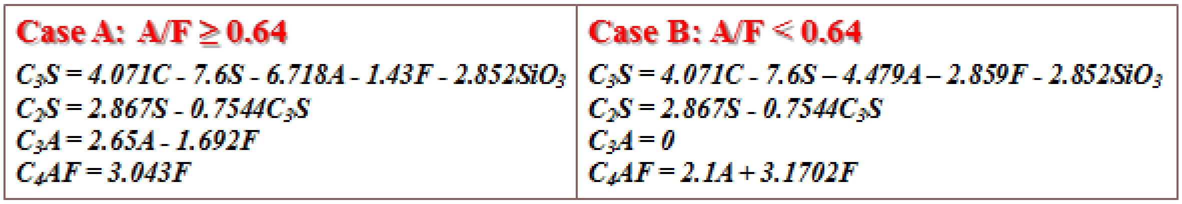
- Gain of strength due to C_2S with in 2-3 weeks is only 15% of that of C_3S.
- Gain of strength after 28 day is almost entirely due to C_2S.
- If high strength concrete is required at a later stage , cement should contain higher content of C_2S.

C_3A

- Responsible for initial setting of cement.
- Generates greater heat & hence higher percentage is undesirable.
- Does not contribute to the gain of strength.

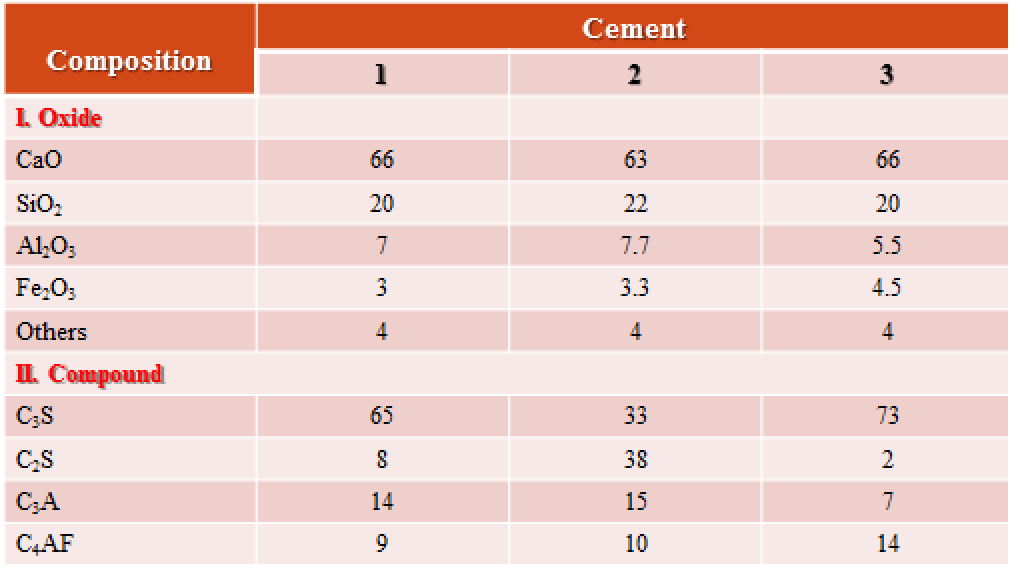
Determination of compound composition

Although it is possible to determine the compound composition by direct analysis, the methods employed are complex and require special skills and expensive equipment. Therefore, it is usually estimated by calculation using the ideal compound stoichiometries and an oxide analysis determined by standard method. The calculation of the phases from the composition is known as Borgue calculation.



Case A: $A/F \geq 0.64$	Case B: $A/F < 0.64$
$C_3S = 4.071C - 7.6S - 6.718A - 1.43F - 2.852SiO_3$	$C_3S = 4.071C - 7.6S - 4.479A - 2.859F - 2.852SiO_3$
$C_2S = 2.867S - 0.7544C_3S$	$C_2S = 2.867S - 0.7544C_3S$
$C_3A = 2.65A - 1.692F$	$C_3A = 0$
$C_4AF = 3.043F$	$C_4AF = 2.1A + 3.1702F$

It should be noted that small changes in oxide composition of the raw materials leads to considerable changes in the proportion of the compounds.



Composition	Cement		
	1	2	3
I. Oxide			
CaO	66	63	66
SiO_2	20	22	20
Al_2O_3	7	7.7	5.5
Fe_2O_3	3	3.3	4.5
Others	4	4	4
II. Compound			
C_3S	65	33	73
C_2S	8	38	2
C_3A	14	15	7
C_4AF	9	10	14

Hydration of Portland cement

Hydration of Portland cement is the chemical reaction it undergoes when brought in contact with water. Unlike the reaction of the other calcareous cements, hydration of Portland cement is a far more complex phenomenon. The reaction of cement with water is ,in the first instance, a reaction of individual compounds. This reaction occurs in two ways:

- Recombination of the dehydrated compounds with water i.e. A direct addition of molecules water to the chemical compounds.

  E.g. $CaSO_4.½\ H_2O \qquad CaSO_4.2H_2O$

- Hydrolysis , leads to chemical changes

E.g. $CaO + 2H_2O \qquad Ca(OH)_2 + H_2O$

Hydration is an exothermic process where heat is liberated. In hydration of cement, its compounds are hydrated mainly towards hydrated calcium silicate (CSH gel) and calcium hydroxide ($Ca(OH)_2$) , with the remaining products being aluminous and ferrites.

Hydration of the pure compounds

I. C_3S: undergoes hydrolysis when mixed with water:

$$2C_3S + 6H \rightarrow C_3S_2H_3 + 3Ca(OH)_2$$

The corresponding weight being

101 24 → 75 + 49

C_3S is the major compound of clinker and the one, which determines to a great extent the progress of setting and hardening. The presence of $Ca(OH)_2$ makes cement paste highly alkaline (pH=12.5). This is the reason why OPC pastes are sensitive to acid attacks and the high PH index also makes cement paste provide good protection to embedded steel against corrosion. C_3S provides cement with early and long-term strengths.

II. C_2S

In water, C_2S also undergoes hydrolysis:

$$2C_2S + 4H \rightarrow C_3S_2H_3 + Ca(OH)_2$$

The corresponding weight being

100 21 → 99 + 22

Both silicates require approximately the same amount of water for their hydration. The effectiveness of C_2S is lower compared to the one of C_3S. C_3S produces more than twice as much $Ca(OH)_2$ as is formed by hydration of C_2S. C_2S gives to the cement long-term strengths.

III. C_3A

Pure C_3A reacts with water very rapidly and immediately converts to a stiff paste.

$$C_3A + 6H \rightarrow C_3AH_6 \quad \text{(calcium aluminate hydrate)}$$

The corresponding weight proportions are:

$$100 + 40 \rightarrow 140$$

In cement, however C_3A hydrates differently due to the presence of gypsum

$$C_3A + 3CaSO_4.H_2O + 26H \rightarrow C_6AS_3H_{32} \quad \text{(ettringite)}$$

$$2C_3A + C_6AS_3H_{32} + 4H \rightarrow 3C_4ASH_{12} \quad \text{(calcium monosulfoaluminate)}$$

IV. C_4AF

$$C_4AF + 2CH + 10H \rightarrow C_3AH_6 + C_3FH_6$$

$$C_4AF + CaSO_4.2H_2O + Ca(OH)_2 \rightarrow C_3(AF).3CaSO_4 \text{ (aq)}$$

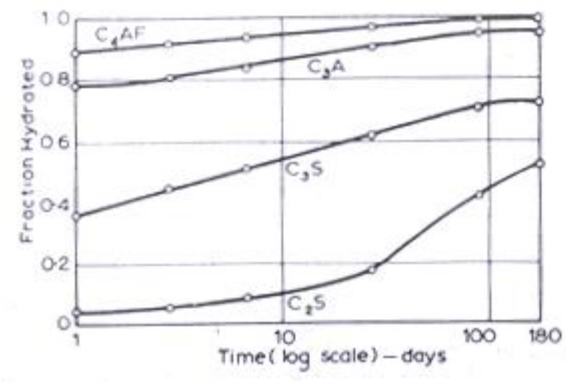
Progress of hydration

The exact manner by which hydration progress and bond development is not fully understood.

1. Newly produced hydrate forms an envelope which grows from within.
2. Dissolved silicates may pass through the envelope and precipitate as an outer layer.
3. Colloidal solution may precipitate through out the mass after the condition of saturation has been reached.

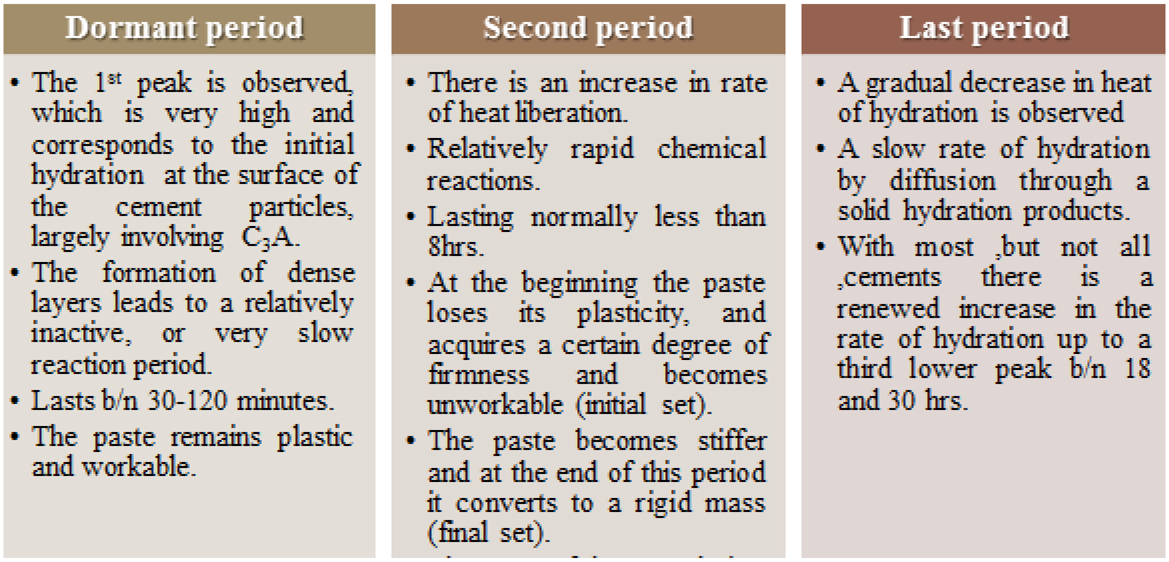
Mechanism of hydration and setting

In cement the C_4AF, C_3A and the C_3S react quickly at first, whereas the C_2S reacts with water slowly. The gypsum (SO_3) and alkalis (Na_2O+K_2O) in cement also commence to dissolve rapidly. The whole process results in a two phase system, one solid and the other liquid, which form the fresh cement paste.

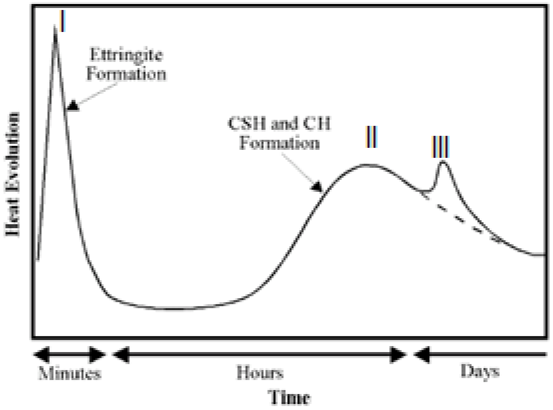


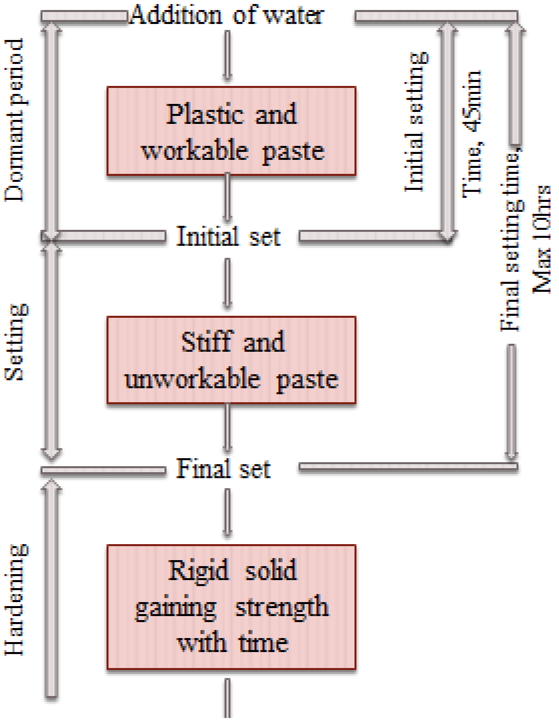
Development of hydration of pure compound: Mechanism of hydration and setting

The liquid phase is essentially a solution of hydroxide and sulphate of calcium and alkalis. The liquid phase may predominate in the early stages of hydration whereas the solid state operate during the later stages. The prevention of solubility of alumina in cement paste is important, since the passage of alumina into solution hinders the normal formation of the hydrated calcium silicates and leads to rapid precipitation of an alumina-silica gel. The instantaneous hydration of aluminates, and hence the untimely loss of plasticity is avoided by adding the required amount of gypsum which will prevent the passage of alumina into solution. Gypsum reacts with C_3A to form a coating of ettringite, a practically insoluble complex compound of needle like crystals ($C_6AS_3H_{32}$). The hydration of the ferrite phase in the presence of gypsum in cement is similar to that of C_3A. As the hydration of cement is an exothermic reaction, the rate of evolution of heat is an indication of the rate of hydration.



Dormant period	Second period	Last period
• The 1st peak is observed, which is very high and corresponds to the initial hydration at the surface of the cement particles, largely involving C_3A. • The formation of dense layers leads to a relatively inactive, or very slow reaction period. • Lasts b/n 30-120 minutes. • The paste remains plastic and workable.	• There is an increase in rate of heat liberation. • Relatively rapid chemical reactions. • Lasting normally less than 8hrs. • At the beginning the paste loses its plasticity, and acquires a certain degree of firmness and becomes unworkable (initial set). • The paste becomes stiffer and at the end of this period it converts to a rigid mass (final set).	• A gradual decrease in heat of hydration is observed • A slow rate of hydration by diffusion through a solid hydration products. • With most ,but not all ,cements there is a renewed increase in the rate of hydration up to a third lower peak b/n 18 and 30 hrs.





Of the four major compounds those which contribute most to hardening and consequent strength gains are the silicates. C_3S contribute most to strength development of the hardened paste during early age. C_2S influences the gain in strength from one month onwards.

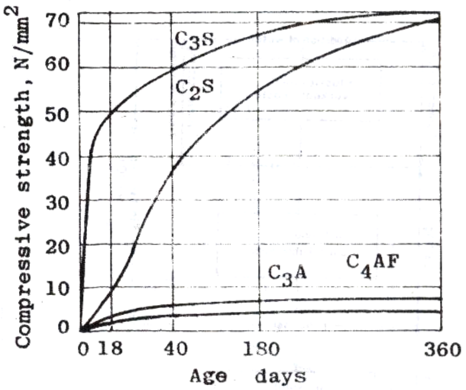
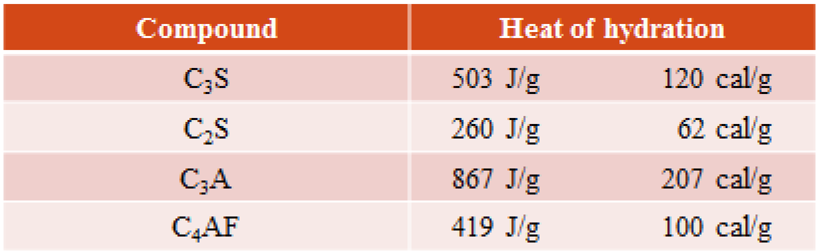


Fig: Development of hydration of pure compound

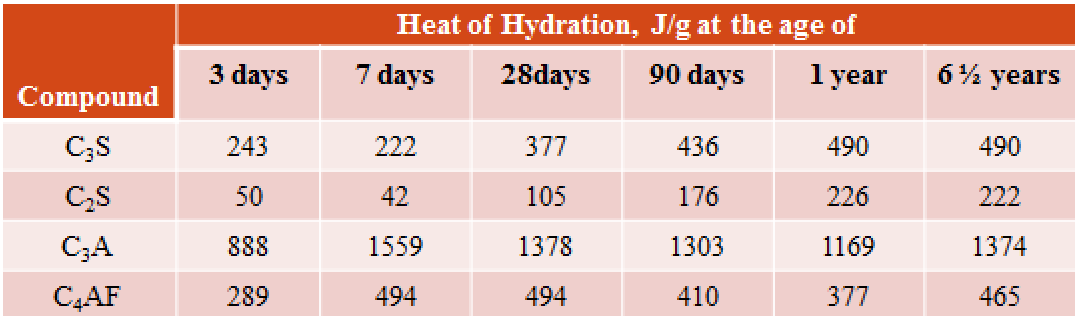
Heat evolution in a setting cement

The hydration of Portland cement is exothermic; i.e. accompanied by liberation of heat which is termed as heat of hydration. For the ordinary Portland cement the heat of hydration varies from 420 to 500 J/g upon complete hydration. About half of the total heat of hydration is librated b/n 1 and 3 days, about three quarter in 7 days, and up to 90% in six months. Among the major compounds, the one that liberate the largest quantity of heat in its pure form is the C_3A.



Compound	Heat of hydration	
C_3S	503 J/g	120 cal/g
C_2S	260 J/g	62 cal/g
C_3A	867 J/g	207 cal/g
C_4AF	419 J/g	100 cal/g

Different compounds hydrate at different rates and liberate different quantities of heat. The hydration process is not an instantaneous one. The reaction is faster in the early period and continues indefinitely at a decreasing rate.



Compound	Heat of Hydration, J/g at the age of					
	3 days	7 days	28days	90 days	1 year	6 ½ years
C_3S	243	222	377	436	490	490
C_2S	50	42	105	176	226	222
C_3A	888	1559	1378	1303	1169	1374
C_4AF	289	494	494	410	377	465

Factors affecting the rate and heat of hydration

The rate of hydration of Portland cement, and hence the heat evolution, are affected by a number of factors which include; cement composition, fineness of cement, water cement ratio, age of paste and ambient condition.

A. Cement composition

At the early stage, the rate of hydration of the constituents in the cement is the same as the rate of hydration of the separate compounds. At the early stage, the speed with which the chemical reaction proceed depends on the affinity of the individual compound to water. The first to react among the cement compounds are the aluminates. The reaction of pure aluminate compounds with water is instantaneous and violent and results in a rapid crystallization and precipitation which intern results in quick setting of the paste. The instantaneous hydration of the aluminates and the ferrites is retarded by the presence of gypsum. The amount of gypsum to properly retard the setting, varies mainly with the content of C_3A and the fineness of cement. At later stages the cement grains become enveloped with layers of hydration products such as CSH gel which grow thicker with age. Hence, at later stage the rate of hydration becomes increasingly dependent on the rate of water diffusion through the layers and less on the rate of hydration of the individual compounds. The total heat of hydration of cement can be approximated from the contribution of the individual constituents by the following equation:

$$Q_H = a(C_3S) + b(C_2S) + c(C_3A) + d(C_4AF)$$

Where: Q_H is the heat of hydration of the cement

a,b,c & d are the heat of hydration contribution of the compounds,

C_3S, C_2S, etc their fractional content in the cement.

Based on statistical analysis of test results the coefficients are determined by researchers:

$$Q_H = 136(C_3S) + 62(C_2S) + 200(C_3A) + 30(C_4AF)$$

The rate of heat evolution of cement, as well as the total heat, is greatly affected by its C_3S and C_3A content and the effects are strongest in the first few hours.

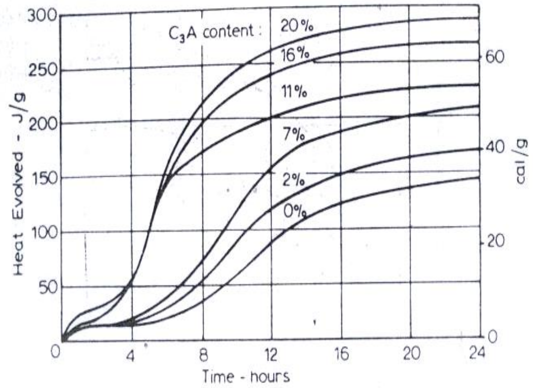


Fig: Effect of C_3A content on heat of hydration of PC

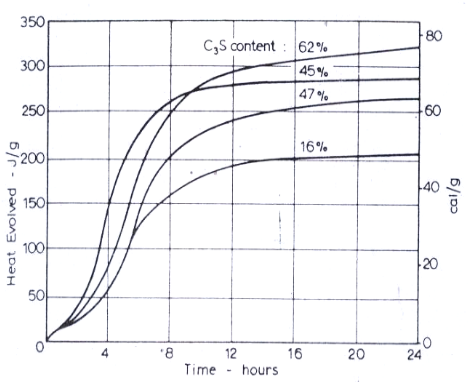
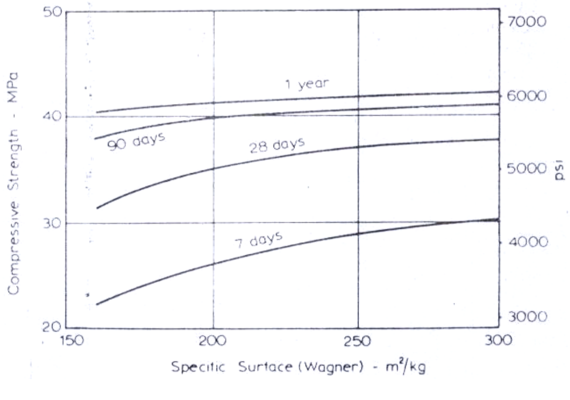


Fig: Effect of C_3S content on heat of hydration of PC

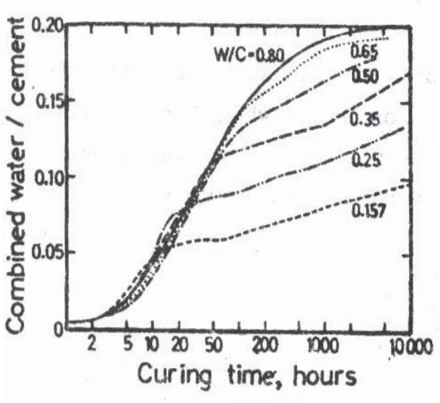
B. Fineness of the cement

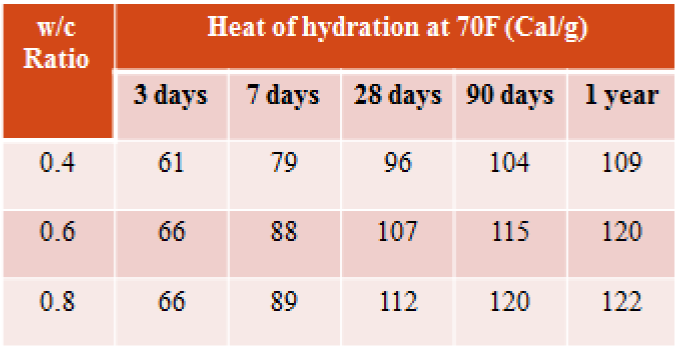
The finer the grinding of the cement, the faster should be the hydration process and vice-versa. A finer cement will require not only more water to cover the higher surface area, but also relatively more gypsum.



C. Water/cement ratio

Both the rate of hydration and the heat evolution are affected by the water/cement ratio. The w/c has practically no influence on the rate of hydration in the first 24 hour. However, later the rate of hydration decreases with a decrease in w/c ratio. The influence of w/c on heat evolution is also marked at later stages.





w/c Ratio	Heat of hydration at 70F (Cal/g)				
	3 days	7 days	28 days	90 days	1 year
0.4	61	79	96	104	109
0.6	66	88	107	115	120
0.8	66	89	112	120	122

Fig: Effect of w/c ratio on the hydration of PC

Fig: Effect of w/c ratio on the heat evolution of PC.

D. Age of paste

The rate of hydration of cements, and hence the heat evolution, is highest at early stage. Depending on the grain size distribution in the cement and the presence of water, hydration may continue for several years after mixing but at a much reduced rate. Hydration stops when the thickness of the layer reaches 25µm.

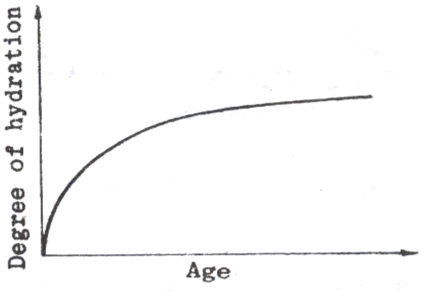


Fig: Degree of hydration Vs age of cement

E. Ambient condition

The rate of hydration of Portland cement is affected by the ambient temperature. The rate of hydration increases with temperature and this is true only at earlier stages.

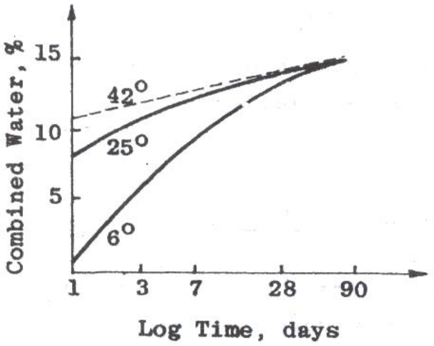


Fig: Effect of ambient temperature on rate of hydration

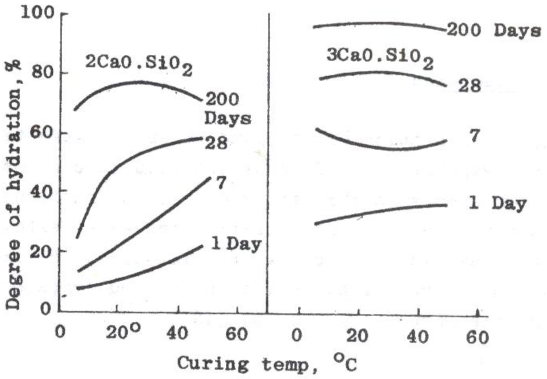


Fig: Effect of ambient temperature on rate of hydration of silicates

Structure of hydrated cement

The setting of a fresh cement gives rise to the formation of internal structure. The internal structure plays a dominant role in determining the strength and other properties of the paste. Almost all of the engineering properties of hardened cement paste and concrete depend on the physical structure of the hydration products rather than their chemical composition. Structure development in a Portland cement paste involves three stages:

- first a solution state,
- second a colloidal stage, and
- third a crystallization stage.

Setting is attributed to the formation of gel, but the subsequent process of hardening is due to the formation of crystallised products.

Development of structure

Two hours after addition of water, the surface of cement grains are coated with gelatinous hydrate material (CSH). The initial set occurs with the development of a weak skeleton in which cement grains are held in place. Final set occurs as the skeleton becomes rigid, cement particles are locked in place, and spacing between cement grains increases due to the volume reduction of the grains, Spaces between the cement grains are filled with hydration products as cement paste develops strength and durability.

Fig: Structure of cement paste constituents

The morphology of the hydration products is found to be very variable:

- Ettringite particles are described as needle like crystals.
- The dominant phase in hardened paste, CSH, is amorphous and comprises both minute fibrous particles and even smaller irregular platelets.
- The micro-crystalline CH, which ordinarily make the second largest phase of the paste, are hexagonal shaped plates.

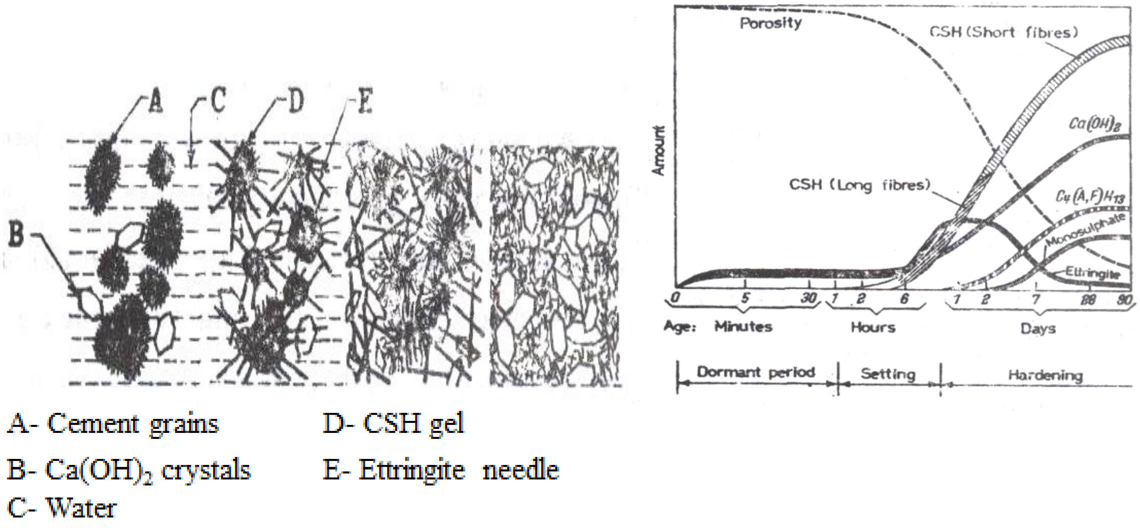
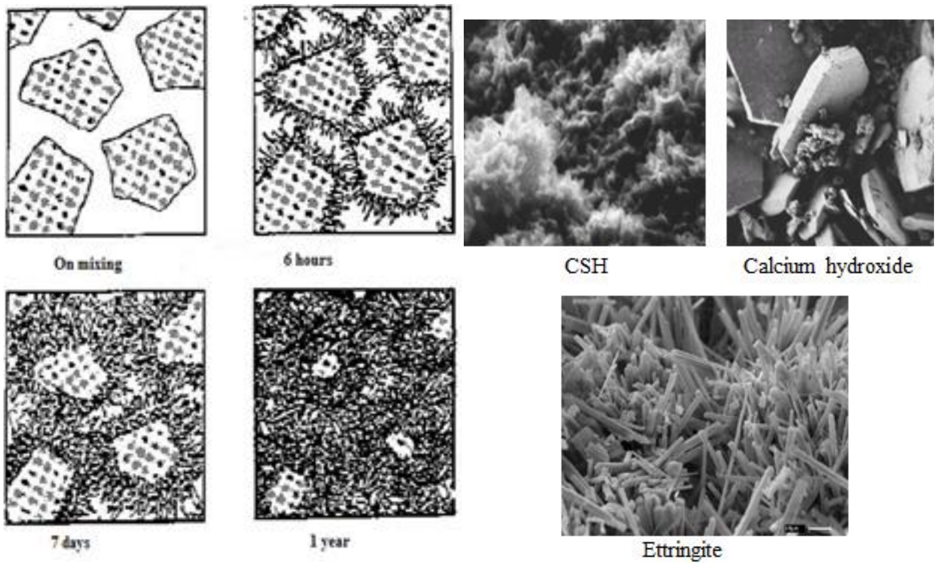


Fig: Schematic description of hydration and structure development



On mixing

6 hours

CSH

Calcium hydroxide

7 days

1 year

Ettringite

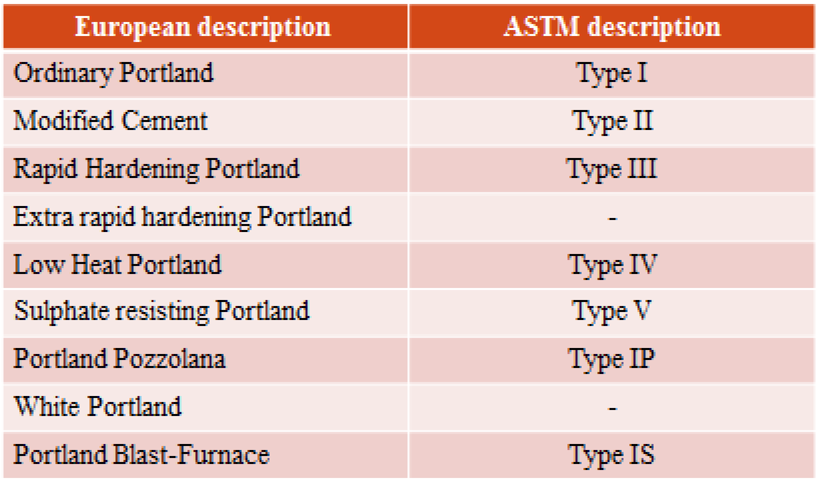
Fig: *CSH production*

Types of Portland cement

The properties of the cement will be influenced by the dominant properties of the individual compounds. Different concrete applications require cement with different properties.

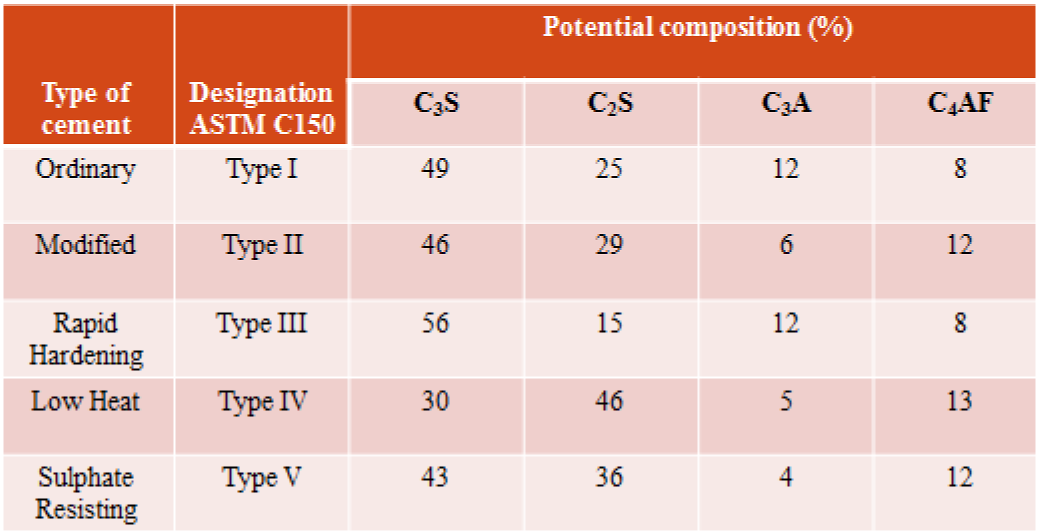
Compounds	Tricalcium silicate (Alites)	Dicalcium silicate (Belite)	Tricalcium Aluminate	Tricalcium aluminoferite (Celite)
Chemical composition (Common Formula)	**$3CaO.SiO_2$ (C_3S)**	**$2CaO.SiO_2$ (C_2S)**	**$3CaO.Al_2O_3$ (C_3A)**	**$4CaO.Al_2O_3.Fe_2O_3$ (C_4AF)**
Rate of hydration	Rapid (hours)	Slow (days)	Instantaneous	Very rapid (minutes)
Heat of hydration	Medium(500J/g)	Low(250/g)	Very high (850)	Medium(420J/g)
Strength development	Rapid (days)	Slow (weeks)	Very rapid (1day)	Very rapid (1day)
Ultimate strength	High	Probably high	Low	Low
Remark	Characteristic constituent of PC.	-	Unstable in water, sensitive to sulphate attack	Imparts to the cement its characteristic grey color.

Different types of cement are achieved by changing the composition of cement (raw materials), fineness of grinding and aadditives (admixtures). In many parts of the world, different types of Portland cement are manufactured for different uses. The main types are:



European description	ASTM description
Ordinary Portland	Type I
Modified Cement	Type II
Rapid Hardening Portland	Type III
Extra rapid hardening Portland	-
Low Heat Portland	Type IV
Sulphate resisting Portland	Type V
Portland Pozzolana	Type IP
White Portland	-
Portland Blast-Furnace	Type IS

Mean values of compound composition of the different Portland cements are as shown below.



Type of cement	Designation ASTM C150	Potential composition (%)			
		C_3S	C_2S	C_3A	C_4AF
Ordinary	Type I	49	25	12	8
Modified	Type II	46	29	6	12
Rapid Hardening	Type III	56	15	12	8
Low Heat	Type IV	30	46	5	13
Sulphate Resisting	Type V	43	36	4	12

Types	ASTM	BS	MS	Properties	Uses
Ordinary Portland Cement	Type I	BS 12:1978	522	▪ Ordinary ▪ 70 % of total cement consumption. ▪ Moderate rate of hardening. ▪ Minimum fineness: 225 m^2/kg	▪ For general concrete construction where special properties are not required. ▪ E.g. floors, pavements, reinforced concrete structures. ▪ By far the most common cement used in general concrete construction when there is no exposure to sulphates in the soil or on groundwater.
Modified Portland Cement (Moderate sulfate resistance)	Type II			▪ Moderate heat of hydration. ▪ Moderate resistance to sulfate attack. ▪ Rate of strength gain is similar to OPC. ▪ Has higher rate of heat development than that of LHPC.	▪ For structures where a moderately low heat generation is desirable or moderate sulfate attack may occur either in soil or sea water e.g. large pier, retaining wall, etc.
Rapid Hardening Portland Cement	Type III		522	▪ Rapid strength. ▪ High C_3S content (70 %). ▪High rate of heat development. ▪ Minimum fineness: 325 m^2/kg. ▪ 3 days strength = 14 days strength of OPC. ▪ Chemical composition relatively the same as OPC. ▪ The setting time of RHPC and OPC is the same.	▪ Urgent/fast track construction (formwork to be removed early). ▪ High early strength is required. ▪ Construction at low temp. ▪ Should not be used in mass concrete construction or in large structural sections because of its higher rate of heat development. ▪ For construction at low temperatures, the use of this cement may provide a satisfactory safeguard against early frost damage.

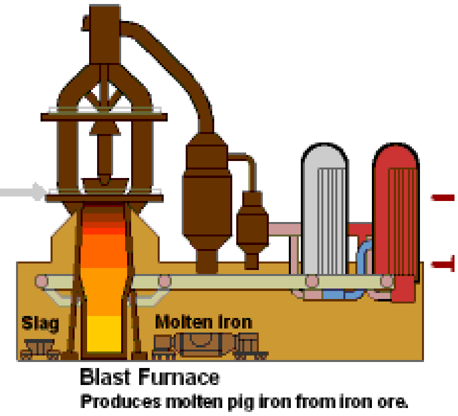
Low Heat Portland Cement	Type IV			▪ Low heat of hydration. ▪ High C_2S and C_4AF. ▪ Low content of C_3S and C_3A resulting in low early strength but ultimate strength is unaffected. ▪ Has a minimum fineness of 325 m^2/kg to ensure a sufficient rate of gain of strength.	▪ For use where it is required that the heat of hydration be a practicable minimum. ▪ Mass concrete structures e.g. large gravity dams. ▪ Prevent thermal and shrinkage cracks.
Sulphate Resisting Portland Cement	Type V		1037	▪ This cement has low C_3A (3.5%) content so as to avoid sulphate attack from outside the concrete. ▪ Minimum fineness: 250 m^2/kg . ▪ The heat developed by SRPC is not much higher than that of low-heat content cement, which is an advantage.	▪ For use where high resistance to the action of sulphate is required. ▪Protection from severe sulfate exposure e.g. underground water/ marine structures. ▪ Active salts are magnesium & sodium sulphates. ▪ Sulphate attack is greatly accelerated if accompanied by alternate wetting and drying, e.g. in marine structure subject to tide or splash. ▪The cost is higher due to special composition of raw materials.
White Portland Cement			888	▪Basically, it is OPC: clinker using fuel oil (instead of coal) and with iron oxide content below 0.4% to ensure whiteness. ▪ Special cooling technique is used. ▪ The property is nearly the same as OPC. ▪White cement is ground finer than grey cement.	▪It is used to enhance aesthetic value, in tiles and for flooring. ▪Building, arts ▪White cement is much more expensive than grey cement.

Blended Portland cement

I. **Portland blast furnace cement (type is)**

A blast furnace is a type of metallurgical furnace used for smelting to produce metals, generally iron. Made by inter-grinding or blending Portland cement clinker with granulated blast slag.

Known also as slag cement. Slag contains lime, silica & alumina, But not in the same proportions as in Portland cement. Minimum fineness is 275 m^2/kg. Early strength is generally lower than OPC and the later strength are similar or even higher. Typical uses are in mass concrete because of low heat of hydration and in seawater construction because of a better sulphate resistance (due to a lower C_3A content) than with the OPC. The surface texture of slag particles tend to be smoother than those of other cements, resulting in an improvement in the workability of the mix. The amount of slag should be between 25-70% of the mass of the mixture.



II. Portland Pozzolana cement (type IP)

Portland Pozzolana cement is manufactured by the intergrinding of OPC clinker with 15-30% pozzolanic material. A Pozzolana is a siliceous or siliceous & aluminous material which itself possesses little or no Cementitious value but will in finely divided form and in the presence of moisture, chemically react with lime (liberated by hydrating Portland cement) at ordinary temperatures to form compounds possessing cementitious properties. Natural Pozzolana are - E.g. Volcanic ash, pumice. Artificial Pozzolana - E.g. fly ash (a product from coal combustion or from coal-fired power station). Portland-Pozzolana cements gain strength slowly and therefore require curing over a comparatively long period, but the long-term strength is high. Can be used in mass concrete construction, E.g. Dam. Advantages of PPC are costly clinker being replaced by cheaper Pozzolanic material- Hence economical, soluble calcium hydroxide is converted into insoluble cementitious products resulting in improvement of permeability, it generates reduced heat of hydration at slow rate and the long term strength of PPC beyond a couple of months is higher than OPC if enough moisture is available.

Testing of cement

Tests are conducted to ensure the quality of cement and determine the chemical and physical properties of cement. Testing of cement can be brought under two categories, which are field testing and laboratory testing.

Field testing is sufficient to subject the cement to field tests when it is used for minor works. The following are the field tests:

A. pen the bag and take a good look at the cement. There should not be any visible lumps. The color of the cement should normally be greenish gray.

B. Thrust your hand into the cement bag. It must give you a cool feeling. There should not be any lump inside.

C. Take a pinch of cement and feel-between the fingers. It should give a smooth and not gritty feeling.

D. Take a hand full of cement and throw it on a bucket full of water, the particles should float for some time before they sink.

E. Take about 100 grams of cement and a small quantity of water and make a stiff paste. From the stiff paste, pat a cake with sharp edges. Put it on a glass plate and slowly take it under water in a bucket. See that the shape of the cake is not disturbed while taking it down to the bottom of the bucket. After 24 hours the cake should retain its original shape and at the same time it should also set and attain some strength.

If the cement satisfies the above field tests it may be concluded that the cement is not bad, however this test does not give any quantitative result.

Laboratory testing

It is incumbent on the part of the user to test the cement in the laboratory to the requirements of the standard specifications with respect to its physical and chemical properties.

Chemical tests

Chemical tests are normally conducted by the manufacturer on regular basis in order to check the quality of the product. They may also be conducted in research laboratories in order to determine the compound composition of the cement used in a research. Chemical tests are of little importance to the ordinary consumer. The results of chemical tests are reported in terms of oxides which are used to calculate the compound composition by Borgue method. Ethiopian Standard ES.C.D6.201 sets quality requirements of Portland Cement as follows:

A. Lime Saturation Factor

The lime saturation factor (L.S.F.) shall not be less than 0.66 or more than 1.02 when calculated by the following formula:

$$\text{L.S.F.} = \frac{\text{CaO} - 0.7(\text{SO}_3)}{2.8(\text{SiO}_2) + 1.2\ (\text{Al}_2\text{O}_3) + 0.65(\text{Fe}_2\text{O}_3)}$$

B. Alumina-Iron Oxide ratio (Al_2O_3:Fe_2O_3)

The ratio of the percentage of alumina to the percentage of iron oxide shall not be less than 0.66. The decrease in the ratio may result from an increase in ferric oxide content which reduces the proportion of C_3A and increases that of C_4AF in the cement.

C. Magnesia (MgO)

The mass of magnesia (magnesium oxide) contained in Portland cement shall not exceed 5.0%. The upper percentage limit is to avoid the long-term unsoundness that results from higher percentage content of MgO.

D. Sulphur trioxide (SO_3)

The mass of sulphur trioxide shall not exceed 3% if the C_3A is 8% or less, and shall not exceed 3.5% if C_3A exceeds 8%. An upper limit of SO_3 is specified in order to avoid unsoundness resulting from the delayed hydration of the sulphate phase.

E. Loss in mass on ignition.

The total loss in mass when Portland cement is heated to a temperature of 925±25^{0}C shall not exceed 4%.

E. Loss in mass on ignition.

The loss in mass on ignition is determined in order to check on possible pre-hydration or carbonation which may result from improper or prolonged storage of the clinker or resulting cement.

F. Insoluble residue.

The mass of insoluble residue shall not exceed 1.5%. The insoluble residue is that part of a cement sample which is insoluble in HCl. It derives from the clay minerals of the raw materials which have not reacted to form the cement compounds which are soluble in this acid. The amount of insoluble residue indicates the efficiency of the burning process, the completeness of the reactions in the kiln.

Physical tests

In addition to the chemical composition, it is required to that Portland cement conforms to the relevant physical requirements for fineness, setting time, soundness and strength.

A. Fineness test

The fineness of cement has an important bearing on the rate of hydration, and hence the rate of gain of strength and also on the rate of evolution of heat. Fineness of cement is tested in two ways; by sieving (rarely used) and by determination of specific surface (total surface area of all the particles in one gram of cement). The specific surface can be determined by the following apparatus: air permeability and blain test.

i. Rigdens flow meter

Product description: Rigdens flow meter

Standard: BS 4359-2 6463-103

Applications: Specific surface (fineness). Constant Volume Method of Rigden.

ii. Air permeability Lea and Nurse

Measure the pressure drop when dry air flows at a constant velocity through a bed of cement of known porosity and thickness. From this the surface area per unit mass of the bed can be related to the permeability of the bed. BS 4550: Part 3: Section 3.3: 1978. Ethiopian Standard ES.D8.490 recommends the use of air permeability apparatus. According to ES, Portland cement must have a specific surface area not less than 2250 cm^2/g when ordinary and not less than 3250cm^2/g when rapid hardening.

iii. Blaine test

A modification of air permeability test. The air does not pass through the bed at a constant rate, but a known volume of air passes at a prescribed average pressure. The rate of flowing diminishing steadily. The time of flow to take place is measured. For a given apparatus and standard porosity, the specific surface can be calculated. Standard: BS 4359-2, EN 196-6 459-2 13286-44, ASTM C204.

B. Specific gravity test

The specific gravity of cement is not determined for its own sake, but it is useful in determining other properties such as the fineness.

Product description: Le Chatelier Flask.

Standard: ASTM C188, AASHTO T133.

Applications: Specific gravity of hydraulic cement, ASTM C188

C. Setting time

Term to describe the stiffening of cement paste or the change from fluid to a rigid state. Cement paste is Cement + Water. Setting mainly caused by a selective hydration of C_3A & C_3S and is accompanied by the temperature rises in the cement paste. Initial set corresponds to a rapid rise of temperature. Initial setting time: is regarded as the time elapsed b/n the moment that the water is added to the cement , to the time that the paste starts losing its plasticity. Final set corresponds to the peak temperature.

Final setting time is the time elapsed b/n the moment that the water is added to the cement , and to the time when the paste has completely lost its plasticity and has attained sufficient firmness to resist certain definite pressure.

False set: different from initial and final set.

: Sometimes occurs within a few minutes of mixing with water.

: No heat is evolved in a false set and the concrete can be remixed without adding water.

Flash set: caused by the rapid reaction between C_3A with water and liberate heat.

: Prevented by the addition of gypsum.

As per ES the minimum initial setting time is 45 minutes where as the maximum final setting time is 10 hours. Final setting time is affected by temperature (20 ± 2^0C) and relative humidity (65-90%).

Product description: Vicat Frame complete.

Standard: EN 196-3, ASTM C187 C191

Applications: Consistence and setting time, EN 196-3, ASTM C187, C191

D. Soundness

It is essential that the cement paste after setting does not undergo a large change in volume i.e. expansion. Expansion may occur due to reactions of free lime, magnesia and calcium sulphate. Free lime hydrates very slowly occupying a large volume than the original free lime oxide. Where as Magnesia: reacts with water in a manner similar to CaO, but only the crystalline form is deleteriously reactive so that unsoundness occurs. Calcium sulphate: cause expansion through the formation of calcium sulphoaluminate (ettringgite) from excess gypsum (not used up by C_3A during setting). Cements exhibiting this type of expansions are classified as unsound. Le Chattelier’s accelerated test is prescribed by BS 4550: Part 3: Section 3.7: 1978 for detecting unsoundness due to free lime only. For OPC, expansion not more than 10 mm. In practice, unsoundness due to free lime is very rare. Autoclave test – ASTM C 151-84 – for testing unsoundness due to magnesia. Calcium sulphate – no specific test is available.

Auto clave test

Le Chattelier's apparatus

E. Strength test

The compressive strength of hardened cement is the most important of all the properties. Strength tests are not made on neat cement paste because of difficulties of excessive shrinkage and subsequent cracking of neat cement. Strength of cement is indirectly found by mortar test and concrete test- BS4550: Part 3

Mortar test:

- Cement : Sand = 1 : 3
- Mass of water = 10% of the mass of dry materials
- Sand – standard sand, one size and spherical shape

Concrete Test:

- Cement : Aggregate = 1 : 6

CHAPTER 4: CONCRETE MAKING MATERIALS AND PLAIN CONCRETE

Introduction

Concrete is a product obtained artificially by hardening of the mixture of; binding material (cement), fine aggregate (sand), coarse aggregate (gravel), admixtures in some cases, and water, in predetermined proportions.

Since concrete is made from different materials which form different parts, it is known as a composite material. The cement and water form a paste that hardens and bonds the aggregates together. Concrete is often looked upon as "man made rock". The property of concrete depend on the characteristic of the ingredients and the proportion of the mix. In mix proportioning workability, strength, durability and economy should be taken into consideration. For practical concrete mixes, the ingredients should be so proportioned that the resulting concrete has the following properties. When freshly mixed it is workable enough for economical and easy uniform placement, but not excessively fluid. When hardened it possess strength and durability adequate to the purpose for which it is intended. It involves minimum cost consistent with acceptable quality.

Functions of the component material

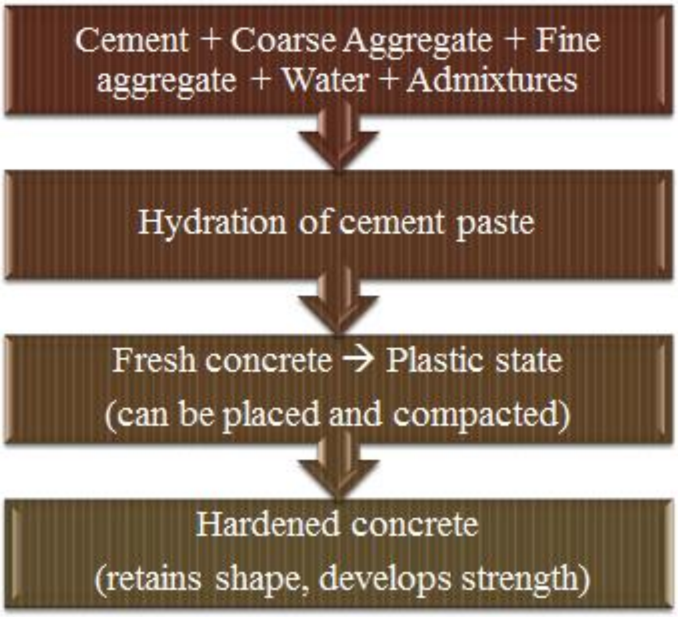
Function of cement: is to react with the water forming a plastic mass when the concrete is fresh and a solid mass when the concrete is hard.

Function of water: Enabling the chemical reactions which cause setting and hardening to proceed. And also lubricating the mixture of aggregates and cement in order to facilitate placing.

Function of the paste: Fills the voids b/n the particles of the inert aggregates and provides lubrication of the fresh plastic mass and upon hardening, it acts as a binder cementing the particles of aggregate together in a permanent solid mass. It also gives strength and water tightness to the hardened mass.

Function of Aggregates: Form the inert mineral filler material which the cement paste binds together and reduce the volume changes resulting from the setting and hardening process and from moisture changes in the paste.

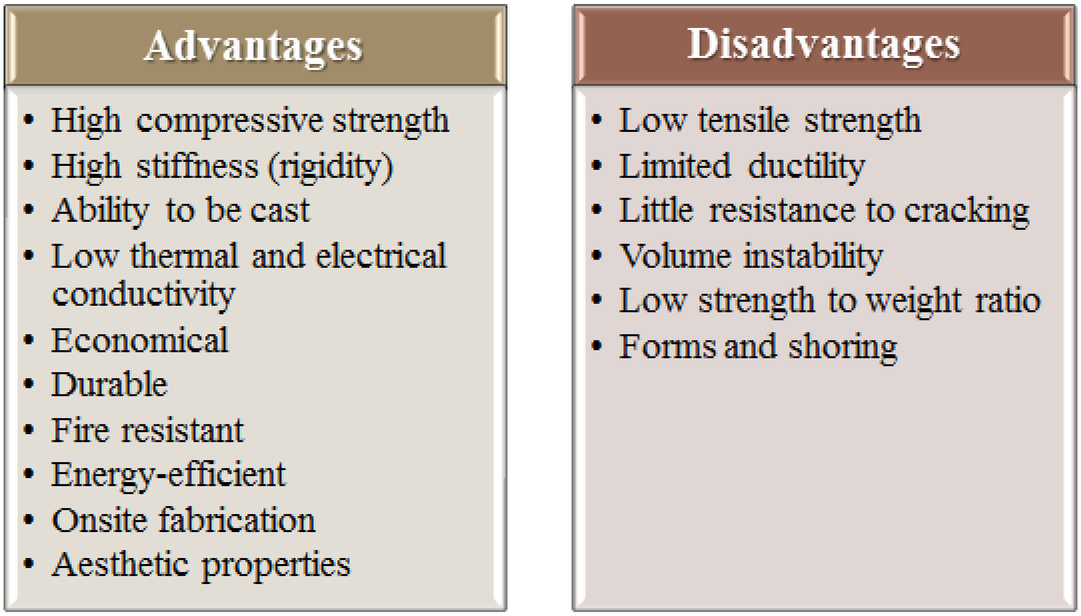
Function of Admixtures: To modify the properties of ordinary concrete so as to make it more suitable for any situation and to change one or more properties of fresh or hardened concrete



Concrete is a material that literally forms the basis of our modern society. Many of the achievements of our modern civilization have depended on concrete. Concrete is the most widely used construction material in the world. It is estimated that the present consumption of concrete in the world is of the order of 10-12 billion tones every year. Humans consume no material except water in such tremendous quantities.

Advantages and disadvantages of concrete

Concrete is a versatile construction material, adaptable to a wide variety of uses.



Advantages

- High compressive strength
- High stiffness (rigidity)
- Ability to be cast
- Low thermal and electrical conductivity
- Economical
- Durable
- Fire resistant
- Energy-efficient
- Onsite fabrication
- Aesthetic properties

Disadvantages

- Low tensile strength
- Limited ductility
- Little resistance to cracking
- Volume instability
- Low strength to weight ratio
- Forms and shoring

Concrete making materials: Aggregate

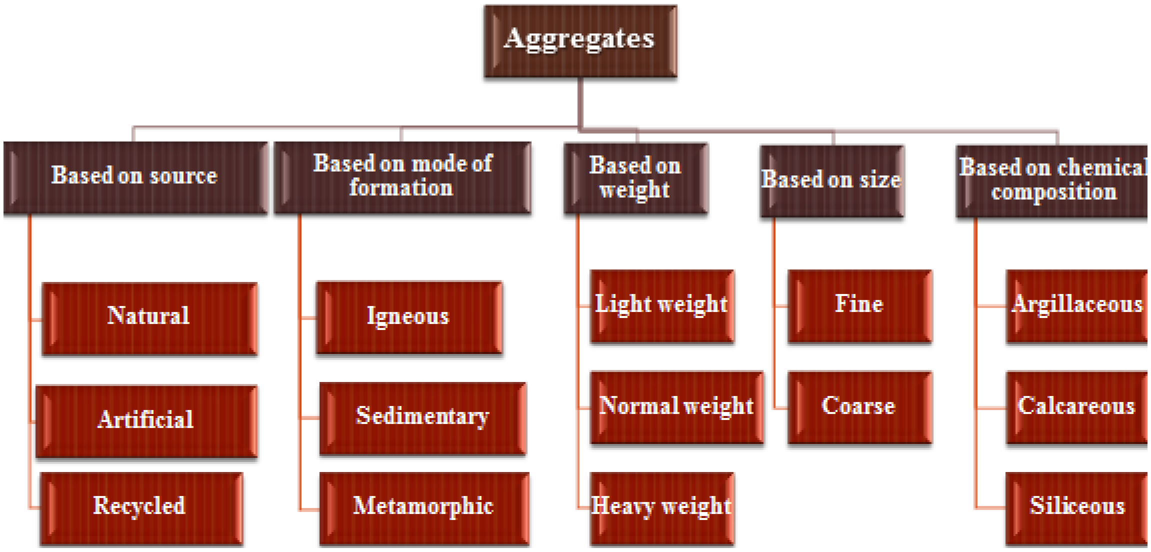
Aggregates are the important constituents in concrete. Aggregates generally occupy 65-75% of the volume of concrete. Hence due consideration should be given in their selection and proportioning. Earlier, aggregates were considered as chemically inert materials but now it has been recognised that their physical, thermal and at times chemical properties influence those of the concrete. Basically aggregate serves the following purposes:

- Form the inert mineral filler material which the cement paste binds together.
- Reduce the volume changes resulting from the setting and hardening process and from moisture changes in the paste.
- Provides better durability than hydrated cement paste alone.
- Economical advantages.

In choosing aggregate for use in particular concrete attention should be given to three important requirements:

- Workability when fresh for which the size and gradation of the aggregate should be such that undue labour in mixing and placing will not be required.
- Strength and durability when hardened for which the aggregate should:
    - ✓ be stronger than the required concrete strength
    - ✓ contain no impurities which adversely affect strength and durability
    - ✓ not go into undesirable reaction with the cement
    - ✓ be resistant to weathering action
- Economy of the mixture: the aggregate should be
    - ✓ available from local and easily accessible deposit or quarry
    - ✓ well graded in order to minimize paste, hence cement requirement.

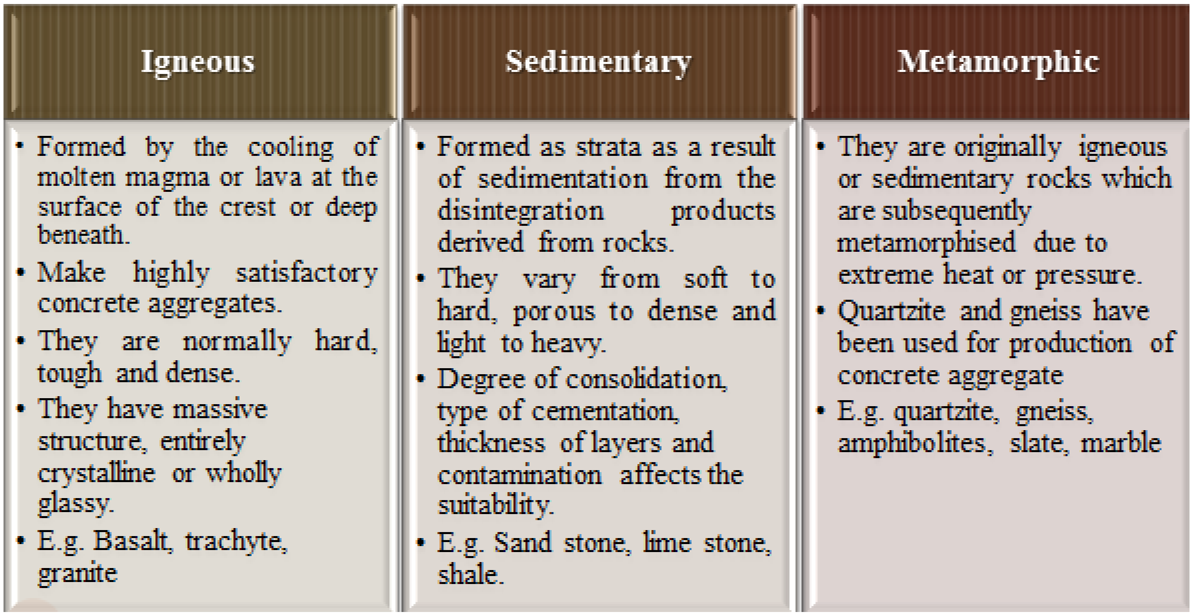
Classification of aggregates



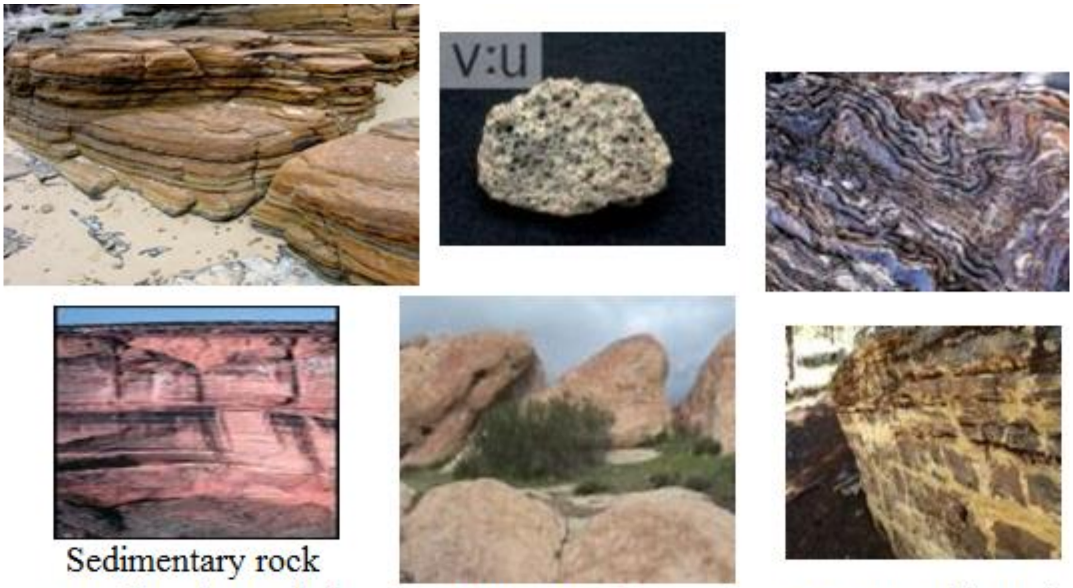
I. Classification based on source

As regards the source aggregates may be natural, artificial or recycled. Natural aggregates are obtained from river beds (sand, gravel) or from quarries (crushed rock). Artificial aggregates are generally obtained from industrial wastes such as the blast furnace slag. Recycled Aggregate – e.g. crushed concrete, clay bricks

II. Classification based on mode of formation



Igneous	Sedimentary	Metamorphic
• Formed by the cooling of molten magma or lava at the surface of the crest or deep beneath. • Make highly satisfactory concrete aggregates. • They are normally hard, tough and dense. • They have massive structure, entirely crystalline or wholly glassy. • E.g. Basalt, trachyte, granite	• Formed as strata as a result of sedimentation from the disintegration products derived from rocks. • They vary from soft to hard, porous to dense and light to heavy. • Degree of consolidation, type of cementation, thickness of layers and contamination affects the suitability. • E.g. Sand stone, lime stone, shale.	• They are originally igneous or sedimentary rocks which are subsequently metamorphised due to extreme heat or pressure. • Quartzite and gneiss have been used for production of concrete aggregate • E.g. quartzite, gneiss, amphibolites, slate, marble



Sedimentary rock
e.g. limestone, shale

Igneous rock
e.g. granite

Metamorphic rock
e.g. marble

III. Classification based on weight

Based on weight aggregates are divided into three groups

A. Heavy weight aggregates: with specific gravity more than four. These includes steel balls, bronze and other metals used in concrete for radiation.

B. Normal weight aggregates: with specific gravity b/n 2.4 and 3.0. E.g. basalt, granite, trachyte, etc.

C. Light weight aggregates: with specific gravity less than 2 such as pumice, scoria, diatomite, etc. which are used to make light weight concrete.

IV. Classification based on size

Aggregate bigger than about 4.75mm in diameter is classified as coarse aggregate (Type CA) and the one smaller as fine aggregate (Type FA).

V. Classification based on chemical composition

Based on chemical composition aggregates are divided into three groups

A. Argillaceous: Composed primarily of aluminum oxide (Al_2O_3) the chief component of clay.

B. Siliceous: Composed primarily of silicon dioxide (Si_2O) the principal ingredient of quartz sand.

C. Calcareous: composed primarily of calcium carbonate or lime ($CaCO_3$).

VI. Classification based on condition

Crushed: From quarry - sharp, angular particles, rough surface, good bond strength, low workability.

Uncrushed: Uncrushed From river - round shapes, smooth surface, low bonding properties, high workability.

Properties of aggregates

Grading of aggregate

The maximum size of aggregate practicable to handle under a given set of conditions should be used. Using the largest possible maximum size will result in:

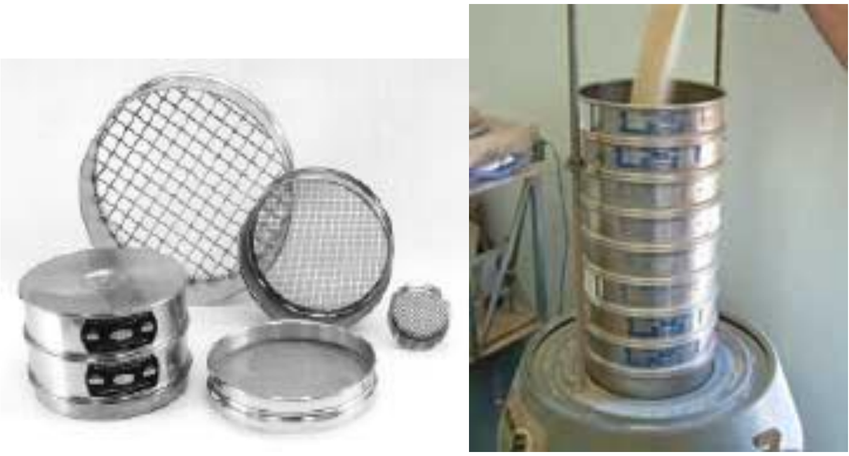
- Reduction of the cement content,
- Reduction in water requirement, and
- Reduction of drying shrinkage.

The maximum aggregate that can be used in any given condition may be limited by the following conditions.

- Thickness of section
- Spacing of reinforcement
- Clear cover
- Mixing, placing and handling techniques.

Fig. 5-4. Range of particle sizes found in aggregate for use in concrete. (8985)

One of the most important factors for producing workable concrete is good gradation of aggregate. Good grading implies that a sample of aggregates contains all standard fractions of aggregate in required proportion such that the sample contains minimum voids. A good gradation secures increased economy, higher strength, lower shrinkage and greater durability. The grading or particle size distribution of aggregate is determined by a sieve analysis. Sieve analysis is the name given to the operation of dividing a sample of aggregate into various fractions each consisting of particles of the same size. A sample of aggregate for sieve analysis is first surface dried and then sieved through the series, starting with the largest. The material retained on each sieve after shaking represents the fraction of aggregate coarser than the sieve in question and finer than the sieve above. The summation of the material retained on the sieves divided by 100 is called the Fineness Modulus (FM). It is used as an index to the fineness or coarseness and uniformity of aggregate supplied.



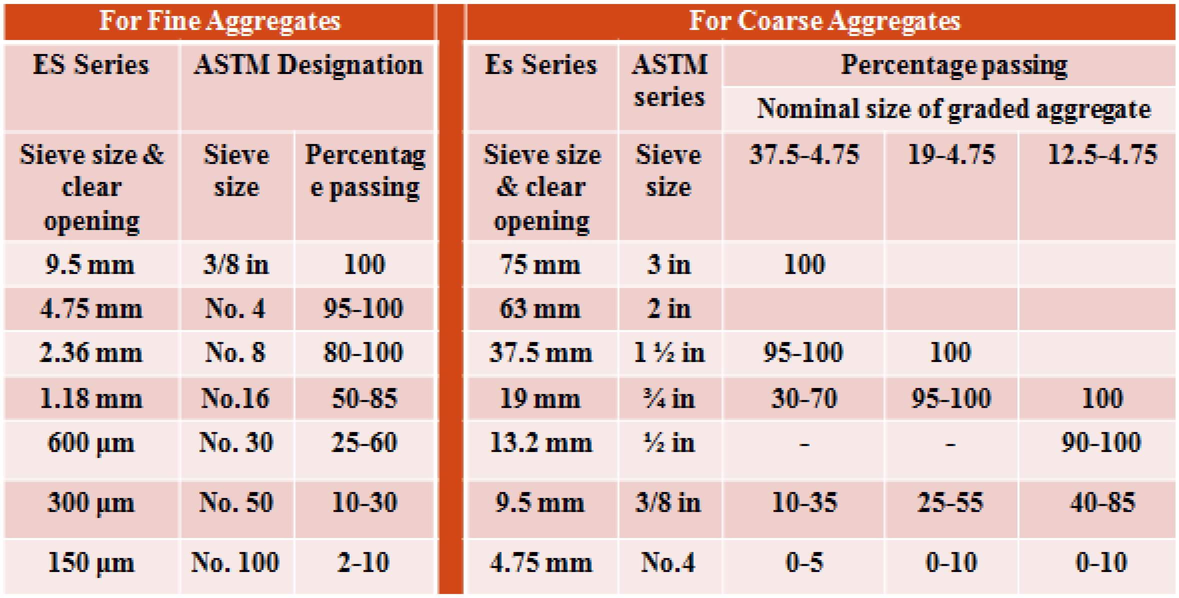
Fine FM b/n ***2.3-2.6***
Medium FM b/n ***2.6-2.9***
Coarse FM b/n ***2.9-3.2***

Fig: Sieve analysis

Standard sieve sizes and square openings

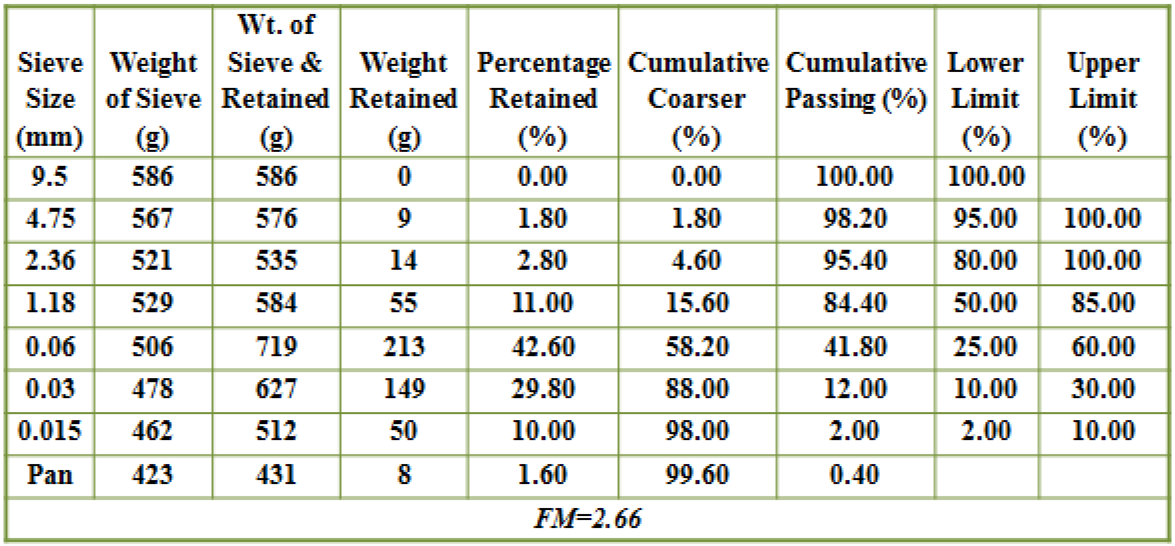
For Fine Aggregates			For Coarse Aggregates		
ES Series	ASTM Series		Es Series	ASTM Series	
Sieve size & clear opening	Sieve size	Clear opening	Sieve size & clear opening	Sieve size	Clear opening
9.5 mm	3/8	0.375 in	75 mm	3 in	3.00 in
4.75 mm	No. 4	0.187 in	63 mm	2 in	2.00 in
2.36 mm	No. 8	0.0937 in	37.5 mm	1 ½ in	1.50 in
-	-	-	-	1 in	1.00 in
1.18 mm	No.16	0.0469 in	19 mm	¾ in	0.75 in
600 µm	No. 30	0.0232 in	13.2 mm	½ in	0.50 in
300 µm	No. 50	0.0117 in	9.5 mm	3/8 in	0.375 in
150 µm	No. 100	0.0059 in	4.75 mm	No.4	0.187 in

Grading requirement for fine and coarse aggregate



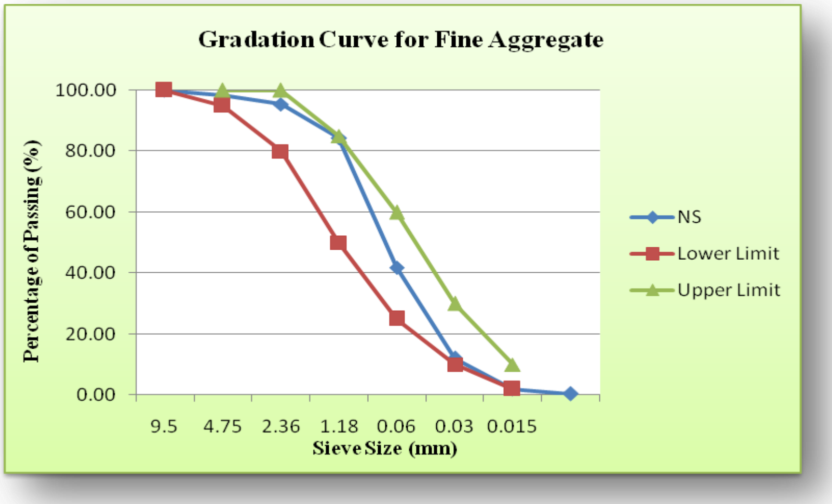
For Fine Aggregates			For Coarse Aggregates				
ES Series	ASTM Designation		Es Series	ASTM series	Percentage passing		
					Nominal size of graded aggregate		
Sieve size & clear opening	Sieve size	Percentage passing	Sieve size & clear opening	Sieve size	37.5-4.75	19-4.75	12.5-4.75
9.5 mm	3/8 in	100	75 mm	3 in	100		
4.75 mm	No. 4	95-100	63 mm	2 in			
2.36 mm	No. 8	80-100	37.5 mm	1 ½ in	95-100	100	
1.18 mm	No.16	50-85	19 mm	¾ in	30-70	95-100	100
600 µm	No. 30	25-60	13.2 mm	½ in	-	-	90-100
300 µm	No. 50	10-30	9.5 mm	3/8 in	10-35	25-55	40-85
150 µm	No. 100	2-10	4.75 mm	No.4	0-5	0-10	0-10

Ex-1 Sieve Analysis Results for Fine Aggregate (sample size = 500g)



Sieve Size (mm)	Weight of Sieve (g)	Wt. of Sieve & Retained (g)	Weight Retained (g)	Percentage Retained (%)	Cumulative Coarser (%)	Cumulative Passing (%)	Lower Limit (%)	Upper Limit (%)
9.5	586	586	0	0.00	0.00	100.00	100.00	
4.75	567	576	9	1.80	1.80	98.20	95.00	100.00
2.36	521	535	14	2.80	4.60	95.40	80.00	100.00
1.18	529	584	55	11.00	15.60	84.40	50.00	85.00
0.06	506	719	213	42.60	58.20	41.80	25.00	60.00
0.03	478	627	149	29.80	88.00	12.00	10.00	30.00
0.015	462	512	50	10.00	98.00	2.00	2.00	10.00
Pan	423	431	8	1.60	99.60	0.40		
FM=2.66								

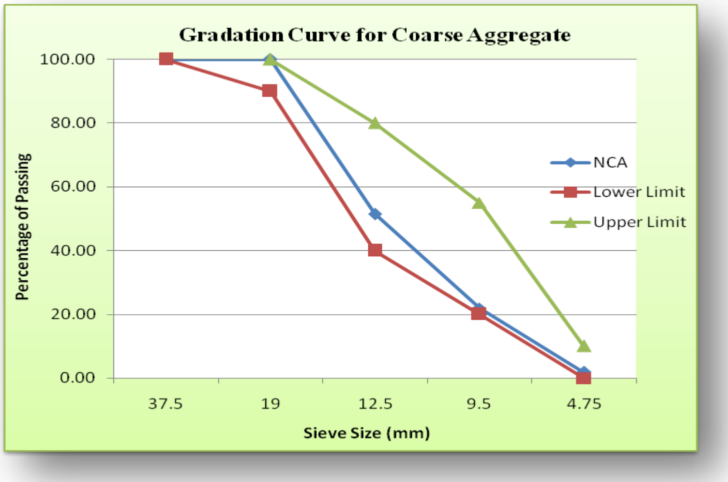
Gradation Curve for Fine Aggregate



Ex-2 Sieve Analysis Results for Coarse Aggregate (sample size = 5108g)

Sieve Size (mm)	Weight of Sieve (g)	Wt. of Sieve & Retained (g)	Weight Retained (g)	Percentage Retained (%)	Cumulative Coarser (%)	Cumulative Passing (%)	Lower Limit (%)	Upper Limit (%)
37.5	1188	1188	0	0.00	0.00	100.00	100.00	
19	1419	1419	0	0.00	0.00	100.00	90.00	100.00
12.5	1166	3645	2479	48.53	48.53	51.47	40.00	80.00
9.5	1171	2682	1511	29.58	78.11	21.89	20.00	55.00
4.75	1194	2222	1028	20.13	98.24	1.76	0.00	10.00
Pan	1060	1150	90	1.76	100.00	0.00	0.00	5.00
FM=2.25								

Gradation Curve for Coarse Aggregate



Combined Grading of aggregate

Aggregate is sometimes analyzed using the combined grading of fine and coarse aggregate together, as they exist in a concrete mixture. The combined gradation can be used to better control workability, pumpability, shrinkage, and other properties of concrete.

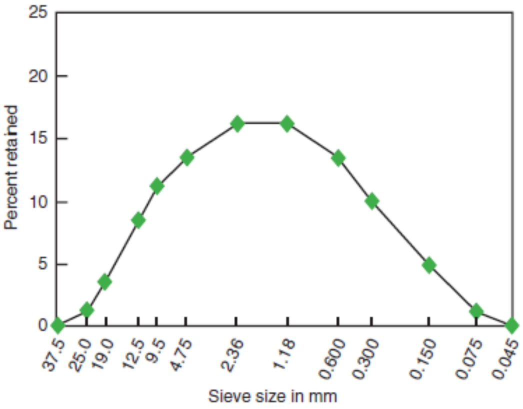


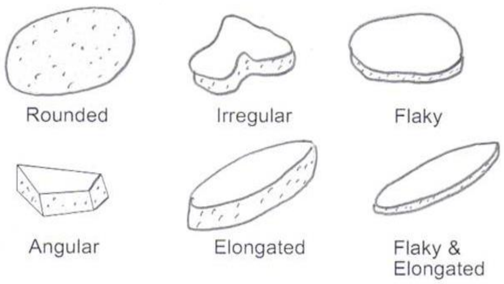
Fig. 5-10. Optimum combined aggregate grading for concrete.

Particle shape

The shape of aggregate is an important characteristic since it affects the workability of concrete. Not only the characteristic of the parent rock, but also the type of crusher used will influence the shape of aggregates. From the standpoint of economy in cement for a given w/c ratio, rounded aggregates are preferable to angular aggregates. Angular aggregates give higher strength and sometimes greater durability as a result of interlocking texture in the hardened concrete. Flat particles in concrete aggregates will have particularly objectionable influence on the workability, cement requirement, strength and durability. In general, excessively flat aggregates make very poor concrete.

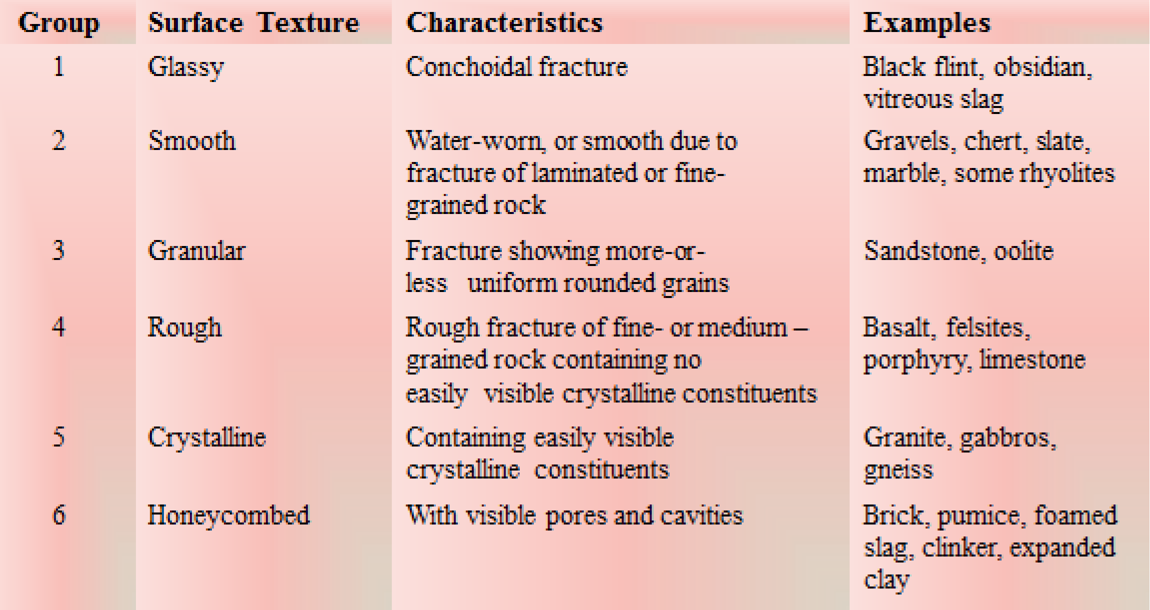
Particle shape

Classification	Description	Examples
Rounded	Fully water –worn or completely shaped by attrition	River or seashore gravel; desert, seashore, and windblown sand
Irregular	Naturally irregular, or partly shaped by attrition and having rounded edges	Other gravels; sand or dug flint
Flaky	Material of which the thickness is small relative to the other two dimensions	Laminated rock
Angular	Possessing well-defined edges formed at the intersection of roughly planar faces	Crushed rocks of all types; talus; crushed slag
Elongated	Material, usually angular, in which the length is considerably larger than the other two dimensions	-
Flaky and elongated	Material having the length considerably larger than the width, and the width considerably larger than the thickness	-



Particle texture

Surface texture is the property, which depends upon the relative degree to which particle surfaces are polished or dull, smooth or rough. Surface texture depends on hardness, grain size, pore structure, structure of the rock, etc. Hard, dense, fine-grained materials will generally have smooth structure surfaces. As surface smoothness increases, contact area decreases, hence a highly polished particles will have less bonding area with the matrix than a rough particle of the same volume.



Group	Surface Texture	Characteristics	Examples
1	Glassy	Conchoidal fracture	Black flint, obsidian, vitreous slag
2	Smooth	Water-worn, or smooth due to fracture of laminated or fine-grained rock	Gravels, chert, slate, marble, some rhyolites
3	Granular	Fracture showing more-or-less uniform rounded grains	Sandstone, oolite
4	Rough	Rough fracture of fine- or medium –grained rock containing no easily visible crystalline constituents	Basalt, felsites, porphyry, limestone
5	Crystalline	Containing easily visible crystalline constituents	Granite, gabbros, gneiss
6	Honeycombed	With visible pores and cavities	Brick, pumice, foamed slag, clinker, expanded clay

Specific gravity

The specific gravity of a substance is ratio b/n the weight of the substance and that of the same volume of water. This definition assumes that the substance is solid throughout. In concrete technology distinction is made b/n absolute specific gravity, apparent specific gravity and bulk specific gravity. Absolute specific gravity: is the ratio of the mass of a unit volume of a material (without pores) to the same volume of gas-free distilled water.

Apparent specific gravity: is the ratio of the weight in air of a material of given volume (solid matter plus impermeable pores or voids) to the weight in air of an equal volume of distilled water.

Apparent specific gravity = A/(A-C)

Bulk specific gravity: is defined as the ratio of the weight in air of a given volume of a permeable material (including both its permeable and impermeable voids) to the weight in air of an equal volume of water.

Bulk specific gravity = A/(B-C)

Bulk specific gravity (SSD basis): is defined as the ratio of the weight in air of a permeable material in a saturated surface dry condition to the weight in air of an equal volume of water.

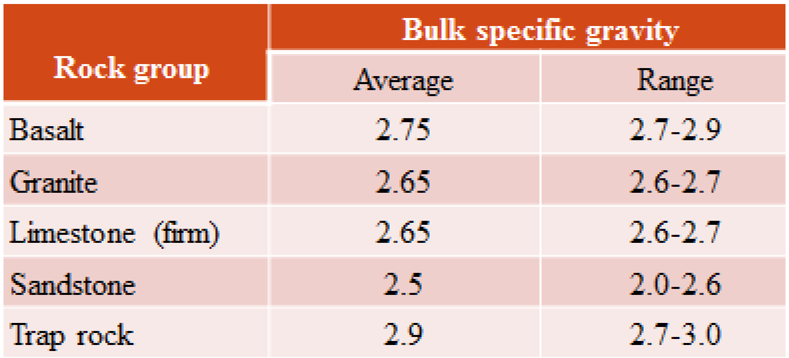
Bulk specific gravity (SSD) = B/(B-C)

Where: A= weight of the oven dry sample in air.

B= weight of SSD sample in air

C= weight of saturated sample in water.

In computation of quantities for concrete mixes it is the specific gravity of the SSD aggregates that is always used.



Rock group	Bulk specific gravity	
	Average	Range
Basalt	2.75	2.7-2.9
Granite	2.65	2.6-2.7
Limestone (firm)	2.65	2.6-2.7
Sandstone	2.5	2.0-2.6
Trap rock	2.9	2.7-3.0

In metric units, the specific gravity of a material is numerically equal to its weight in grams per cubic centimeter (sometimes called solid unit weight).

Bulk density (unit weight)

Bulk density is the weight of the aggregate required to fill a container of a specified unit volume. Volume is occupied by both the aggregates and the voids between the aggregate particles. It is affected by the degree of compaction (voids), aggregate moisture (presence of water), size distribution and shape of particles and how densely the aggregate is packed.

- Loose bulk density
- Rodded or compact bulk density

Material	Kg/m^3
Sand (dry)	1520-1680
Gravel	1280-1440
Crushed stone	1250-1400

Example: In order to determine bulk and apparent specific gravity, and absorption of coarse aggregate, 5 kg of sample was brought from the site and the following weights were recorded at different condition.

Determine i) Moisture Content, ii) Bulk Specific Gravity at saturated-surface-dry basis, iii) Apparent Specific Gravity, and iv) Absorption Capacity.

No.	Description	Weight in gram
1.	Weight of oven dry sample in air = A	4944
2.	Weight of saturated-surface-dry sample in air = B	5029
3.	Weight of saturated sample in water = C	3259

Solution

Let: Weight of oven dry sample in air = A

Weight of saturated-surface-dry sample in air = B

Weight of saturated sample in water = C

i) Moisture Content = 100*(Weight of Sample - A)/A = 100* (5000-4944)/4944 = 1.13%

ii) Bulk Specific Gravity (SSD) = B/(B-C) = (5029)/(5029-3259) = 2.84

iii) Apparent Specific Gravity = A/(A-C) = 4944/(4944-3259) = 2.93

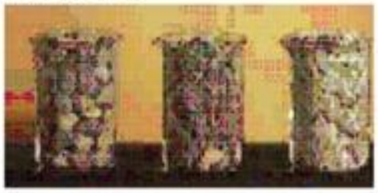
iv) Absorption Capacity = 100*(B-A)/A = 100*(5029-4944)/4944 = 1.72%

voids

Represents the amount of air space between individual particles in a mass of coarse or fine aggregates. The difference b/n solid unit weight and the bulk density indicate the amount of voids b/n the particle.

$$\text{Voids, \%} = \frac{\text{solid unit weight} - \text{bulk density}}{\text{Solid unit weight}} \times 100$$

$$\text{Voids ratio} = 1 - \frac{\text{bulk density}}{\text{Solid unit weight}}$$



Void content affects mortar requirements in mix design; water and mortar requirement tend to increase as aggregate void content increases. Void content between aggregate particles increases with increasing aggregate angularity. Void contents range from 30-45% for coarse aggregates to about 40-50% for fine aggregates. Total volume of voids can be reduced by using a collection of aggregate sizes. The cement paste requirement for concrete is proportional to the void content of the combined aggregate.

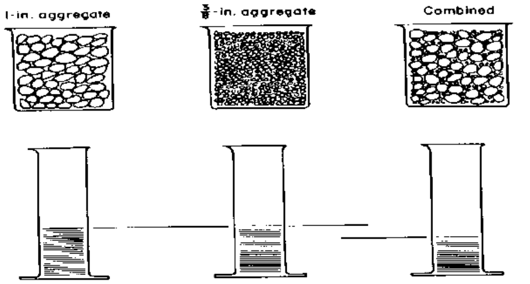
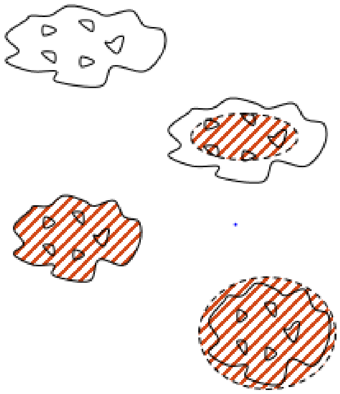


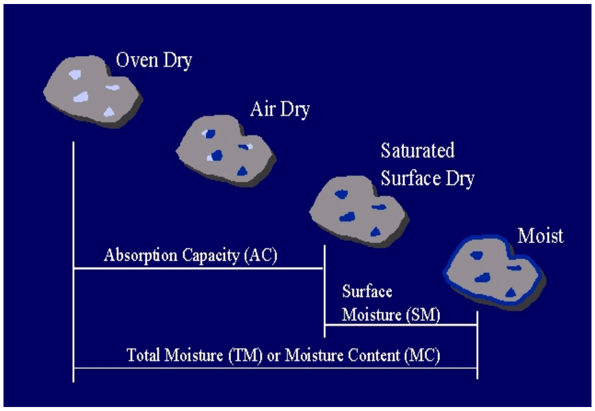
Fig. 4-4. The level of liquid in the graduates, representing voids, is constant for equal absolute volumes of aggregates of uniform but different size. When different sizes are combined, the void-content decreases. The illustration is not to scale.

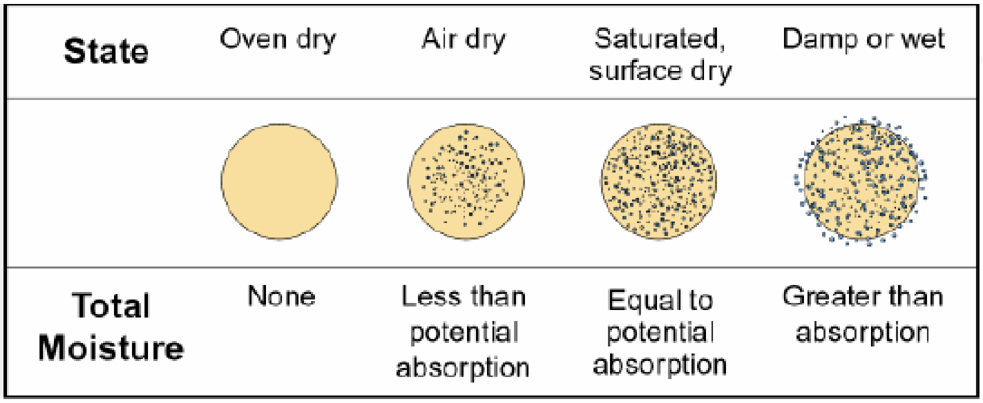
Porosity, absorption and surface moisture

Porosity: is the ratio of the volume of the pores (small holes in aggregate through which water can go inside) in a particle to its total volume. The porosity of aggregate is important since it affects its bulk specific gravity, permeability and absorption which in turn affect the properties of the resulting concrete. Some of the pores are wholly within the solid, and others are on the surface. As regards the moisture content, the various states in which an aggregate may exist are:

- *Oven-dry*: completely dry
- *Air dry:* dry at the surface, some internal moisture, but less than the amount required to saturate the particle.
- *Saturated surface dry condition*: no free moisture on the particle, but all voids with in the particle filled with water.
- *Damp or wet*: saturated and with free or surface moisture on its surface.







State	Oven dry	Air dry	Saturated, surface dry	Damp or wet
Total Moisture	None	Less than potential absorption	Equal to potential absorption	Greater than absorption

Granite aggregate at various moisture conditions

Absorbed moisture: Weight of water absorbed by dry aggregate particles in reaching the saturated surface dry condition. No water on the surface of a particle but all the pores are filled with water.

Absorption Capacity, (%) = $[(W_{SSD} - W_{OD})/W_{OD}] \times 100$

Effective absorption Capacity, (%) = $[(W_{SSD} - W_{air\ dry})/W_{OD}] \times 100$

Effective absorption Capacity, (%) = $[(W_{air\ dry} - W_{OD})/W_{OD}] \times 100$

Surface moisture: The moisture that is in excess of absorbed moisture.

Surface Moisture ,(%) = $[(W_{WET} - W_{SSD})/W_{SSD}] \times 100$

Total moisture content: The total amount of water present on the external and internal surfaces of aggregates.

Total moisture content = Surface moisture + absorbed moisture

Total moisture Content (%) = $[(W_{AGG} - W_{OD})/W_{OD}] \times 100$

The absorption capacity is the measure of the porosity of an aggregate.

Material	Absorption capacity % by weight
Sand	0-2
Gravel	0.5-1
Basalt	0-0.5
Granite	0-0.5
Limestone (firm)	0.5-1
Sand stone	2-7
Trap rock	0-0.5

In calculating or measuring quantities for concrete mix it is important to know the state at which the aggregate is used.

- If it is dry some of the mixing water will be absorbed.
- If it is wet, the free moisture will become a part of the mixing water.

Because of their small size and weight, sand particles are easily pushed and held apart by surface water thereby increasing the total volume per given weight of sand. This phenomenon is known as bulking. The extent of bulking depends on the fineness of the sand, and its free moisture content. The finer the sand the more pronounced the bulking. The volume of the sand goes on increasing with the increase in moisture content up to a certain limit. The effect of bulking of sand should be considered in mix design, especially when volume batching is adopted.

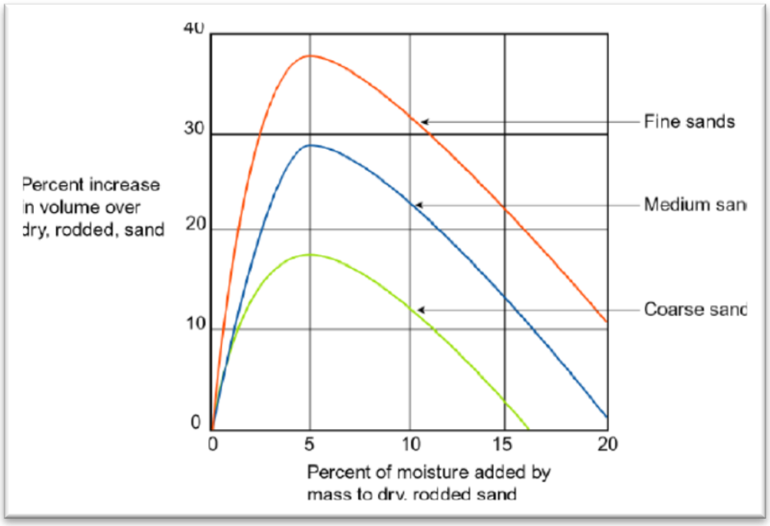


Fig: Bulking due to moisture in fine aggregate

Shrinkage of aggregate

Aggregates with high absorption capacity may have high shrinkage properties on drying.

- Large shrinkage: fine grained sandstones, slate, basalt, trap rock, clay-containing
- Low shrinkage: quartz, limestone, granite, feldspar

Chemical reactivity

Chemical reactions involving aggregate can lead to serious deterioration problems in concrete. Certain forms of silica and siliceous material in aggregate (e.g. chert) interact with alkalis released during the hydration of Portland cement. This produces a gel like material which increases in volume in the presence of water causing expansion and cracking of concrete.

Factors which promote alkali aggregate reaction:

i. Reactivity type of aggregate
ii. High alkali content in cement
iii. Availability of moisture
iv. Optimum moisture condition

Alkali-aggregate reaction can be controlled:

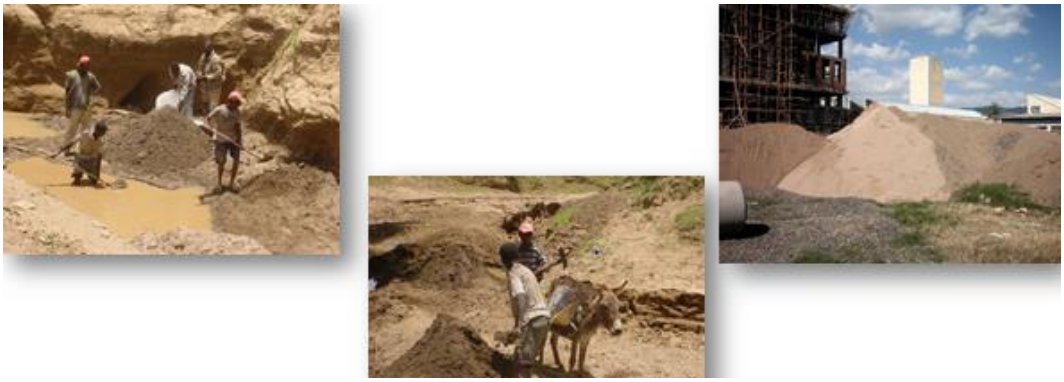
- Selection of non-reactive aggregate
- By the use of low alkali cement
- By controlling the void space in concrete
- By controlling moisture condition and temperature
- By the use of corrective admixtures such as pozzolana

Testing of aggregates

The different types of tests conducted on aggregate for determination of flakiness index, elongation index, inorganic impurities, specific gravity, bulk density and voids, porosity and absorption, bulking of sand, sieve analysis, aggregate crushing value, ten percent value, aggregate impact value and abrasion value.

Fine aggregate

Production of sand in Ethiopia is very primitive. Sand production sites are not mechanized. The production is done by local people of the area using traditional method of collecting the sand from the river bed by donkey



Water

Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. In the production of concrete, water is used for the chemical reaction with cement, workability of concrete, washing aggregate and curing process of concrete.

A popular yard stick to the suitability of water for mixing concrete is that, if water is fit for drinking it is fit for making concrete. It should be Free from impurities such as suspended solids, silt, clay, acids, alkalis, organic matters and dissolved salts.

Effect of impure water

A. For Concrete: These impurities may adversely affect the properties of concrete, e.g. setting time, strength and long term durability. Chloride ions (e.g. from sea water) can accelerate corrosion of reinforcing steel.

B. For washing aggregates: It affect strength and durability. Harmful substances deposits on the surface of the particles.

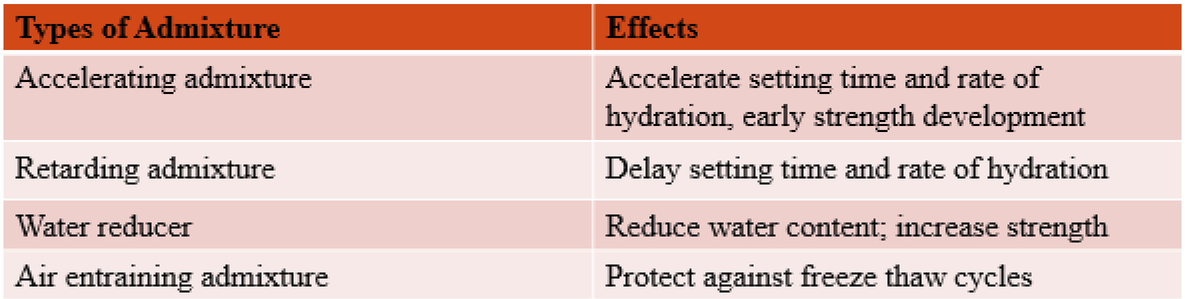
C. For curing concrete: No harmful effects but may spoil its appearance.

Admixtures

Admixture is a material added to plastic (fresh) concrete or mortar before or during mixing. To change one or more properties of fresh or hardened concrete. When the desired modification of properties of fresh or hardened concrete cannot be achieved by changing the composition of the mix proportion or by using different types of cement.

Types of admixtures

- Chemical admixtures:
- Mineral/Pozzolanic admixtures



Types of Admixture	Effects
Accelerating admixture	Accelerate setting time and rate of hydration, early strength development
Retarding admixture	Delay setting time and rate of hydration
Water reducer	Reduce water content; increase strength
Air entraining admixture	Protect against freeze thaw cycles

Other varieties of admixture fall into the specialty category e.g. as a corrosion inhibitor, shrinkage reduction, improve workability, etc.

Accelerators

$CaCl_2$ (most common). Amount added < 2 % of cement weight. Non-chloride admixtures e.g. calcium nitrate.

Application:- it is used in cold-weather condition, rapid removal of formwork or urgent repair work.

:When early strength is required. Compressive strength at 3 days at least 25 % higher than normal concrete.

Problem: Large dosage of $CaCl_2$ cause severe corrosion to steel reinforcement.

: increase heat of hydration and drying shrinkage (One type of concrete cracks).

Retarders

Delay concrete setting time. Lignin, Borax, Sugar and Hydroxyl acid can be taken as an example,

Application: High temperature For large structures and difficult situation (e.g. require longer time for difficult pour)

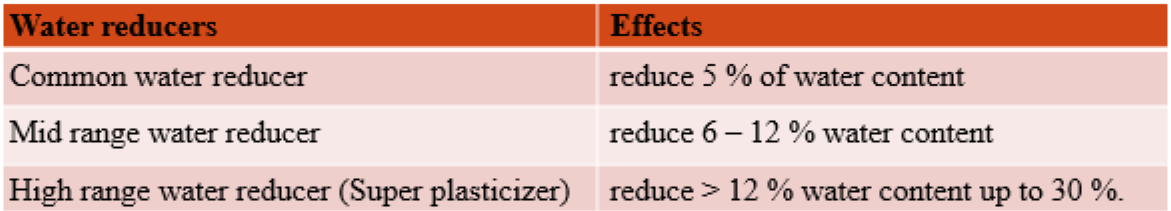
: Keep concrete workable during placing (eliminate cold joint)

Problem: May reduce the strength of concrete at early age. The admixture is based on lignosulfonate (a by product of wood industry) & hydro-carboxylic (HC) acids.

Advantages: Increase strength by reducing quantity of mixing water

: To improve the workability of concrete

: To attain saving in the cement content



Water reducers	Effects
Common water reducer	reduce 5 % of water content
Mid range water reducer	reduce 6 – 12 % water content
High range water reducer (Super plasticizer)	reduce > 12 % water content up to 30 %.

Water reducers (Superplasticizer (High range water reducer))

Added in a small dosage with mixing water (~ 0.2% by cement weight). Increase strength by reducing quantity of mixing water. Produce flowing concrete (suitable for difficult placement problem. E.g. tight constricted form work or dense reinforcement bar (rebar) configuration, or where the concrete must be pumped over a long distance. Produce smooth surface concrete and less likely to chip and spall. Water cement ratio (W/C) ~ 0.3 to 0.45 is possible. And it increases cost by 5% BUT savings in labor can be as high as 33%.

Air entraining admixtures

Liquid chemicals added during mixing to produce microscopic disconnected air bubbles in concrete. It has 20 µm – 200 µm air bubbles in diameter in 0.1-0.2 mm spacing. Admixture from wood resins, petroleum acids, animal & vegetable fats and synthetic detergents. Foaming agents entrain 3% - 10% of air.

Advantages : Improve workability

: Reduce bleeding & segregation

: Increase durability of concrete. Protect concrete from freeze-thaw cycle damage.

Disadvantages: Lower compressive strength

Mineral admixtures (Supplementary cementing materials)

Sources: Natural Pozzolanic materials or industrial by-products.

: Added in relatively large quantities in comparison with chemical admixtures.

: Replace part of the cement content and can be added during concrete mixing process or grind together with cement (Pozzolana cement / blended cement)

Effect of pozzolanic admixtures on concrete: Lower early strength but higher ultimate strength

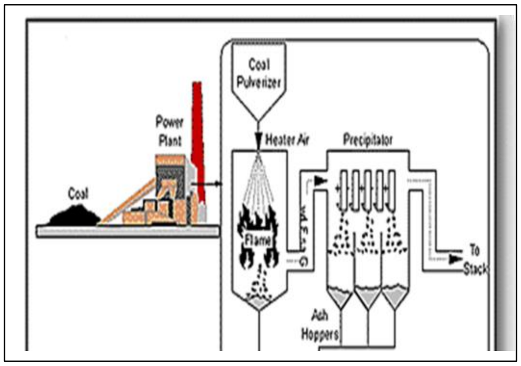
: Lower heat of hydration and less permeable

: More durable – less sulfate attack and Alkali-silica reaction (ASR)

: Reduce cost & increase workability

Example of pozzolanic admixture: Ash, Fly Slag, Silica Fume

Rice Husk Ash & Palm Oil Fuel Ash



Fly ash (pulverized fuel ash)

- By-product of burning powdered coal.
- Finer than Portland cement. Consists mainly of small spheres of glass of complex composition involving silica, ferric oxide and alumina.

Silica fume

- By-product of the electric arc furnaces in the silicon metal and ferrosilicon alloy industry.
- Consists of non-crystalline silica (85% - 90% silicon dioxide)
- Very fine particles – less than 0.1 µm or 100 times finer than Portland cement.

Ground Granulated Blastfurnace Slag (GGBS)

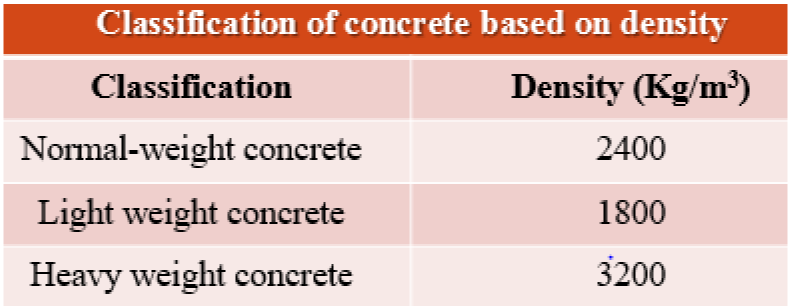
- Granulated blast furnace slag is the material formed when molten blast furnace slag is rapidly chilled by immersion in water.

Types of Concrete

Concrete works are classified as:

- Class I - works under the direction of qualified supervisor
- Class II – works with lower level of quality

Classification based on density: Based on density, concrete is classified as normal weight, light weight, and heavy weight concrete.



Classification of concrete based on density	
Classification	**Density (Kg/m^3)**
Normal-weight concrete	2400
Light weight concrete	1800
Heavy weight concrete	3200

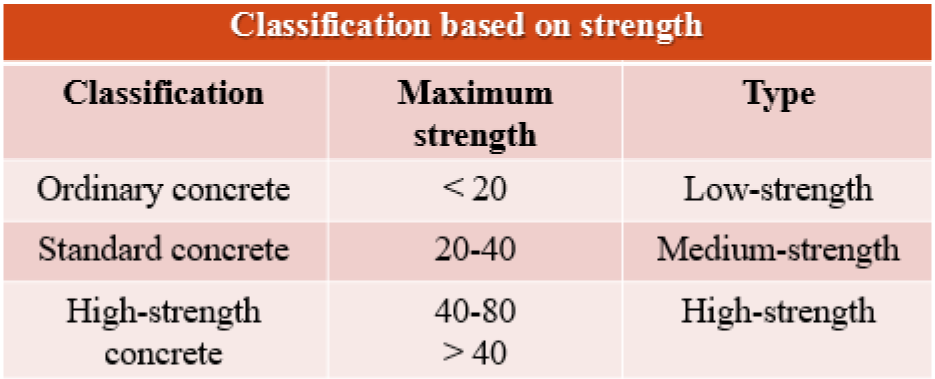
The aggregate used in making concrete contribute mainly to its density. Normal weight concrete is produced using natural sand and crushed aggregate.

For light weight concrete, either light weight aggregates such as pumice, scoria, diatomite, etc. or pyro-processed aggregates are used. These concretes are used for application in which the load of gravity is to be reduced.

Heavy weight concrete is produced using high density aggregate such as hematite or scrap steel pieces. These concretes are used for radiation shielding or increasing the weight of the structure for stability purpose.

Classification based on strength

Concrete can be classified on the basis of strength as follow:



Classification based on strength		
Classification	**Maximum strength**	**Type**
Ordinary concrete	< 20	Low-strength
Standard concrete	20-40	Medium-strength
High-strength concrete	40-80 > 40	High-strength

There are also many other special concretes such as fiber reinforced concrete (FRC), self compacted concrete (SCC), roller compacted concrete, etc.

Special Types of Concrete

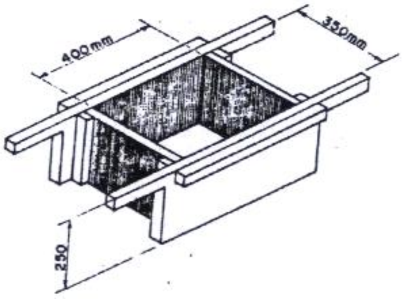
Process of manufacturing of concrete

Production of quality concrete requires thorough care exercised at every stage of manufacture of concrete. The various stages of manufacture of concrete are batching, mixing, transporting, placing, compacting, curing and finishing.

A. **Batching**

The measurement of materials for making concrete is known as batching. There are two methods of batching: volume and weight batching.

i. Volume batching: Volume batching is not a good method for proportioning the material because of the fact that the quantity of solid materials in a container very much depends on its degree of compaction. Volume of moist sand in a loose condition weighs much less than the same volume of dry compacted sand. Volume batching is used for unimportant concrete or for any small job. Cement is always measured by weight. The volume of one bag of cement is taken as 35 litres. Gauge boxes are used for measuring the fine and coarse aggregates. The volume of the box is made equal to the volume of one bag of cement.



ii. Weigh batching: is the correct method of measuring materials. For important concrete, invariably, weigh batching system should be adopted. Use of weigh system in batching, facilitates accuracy, flexibility and simplicity.

Weigh Batcher

B. Mixing

Thorough mixing of the materials is essential for the production of uniform concrete. The mixing should ensure that the mass becomes homogeneous, uniform in colour, and consistency. There are two methods adopted for mixing concrete.

i. Hand mixing
ii. Mechanical mixing (machine mixing)

i. **Hand mixing:** is practiced for small scale unimportant concrete works. As the mixing cannot be thorough and efficient, it is desirable to add 10% more cement to cater the inferior concrete produced by this method. Hand mixing should be done over an impervious concrete or brick floor, a wooden water tight platform or steel mixing trough of sufficiently large size to take one bag cement. Spread out the measured quantity of coarse and fine aggregate in alternate layers. Pour the cement on top of it, and mix them dry by shovel, turning the mixture over and over again until uniformity of colour is achieved. This uniform mixture is spread in thickness of about 20cm, and water is sprinkled over the mixture and simultaneously turned over. This process is continued till such time a good uniform, homogeneous concrete is obtained.

ii. **Machine mixing:** obviously gives better and uniform mixes than hand mixing. it is generally preferred and recommended for reinforced concrete work and for medium or large scale mass concrete work. Machine mixing is not only efficient, but also economical, when the quantity of concreted to be produced is large. Many types of mixers are available for mixing concrete. They can be classified as batch-mixers and continuous mixers. Batch mixers produce concrete, batch by batch with time interval. Continuous mixers produce concrete continuously without stoppage till such time the plant is working. Continuous type is used for large works whereas in normal concrete work, it is the batch mixers which are used. Batch mixer may be of pan type or drum type. The drum type may be further classified as tilting, non-tilting, reversing or forced action type.


Drum mixer


Pan Mixer


Ready mixed

About 25% of the total quantity of water required for mixing, should be introduced to the mixer drum to wet the drum and to prevent any cement sticking. About half the quantity of coarse aggregate is placed in the drum over which about half the quantity of fine aggregate is poured. On that, the full quantity of cement i.e. One bag is poured over which the remaining portion of coarse aggregate and fine aggregate is deposited in sequence. Mixing should continue until the sand particle and all the coarse aggregate are completely coated with thoroughly mixed paste and mortar respectively.

Mixing Time

Concrete mixers are generally designed to run at a speed of 15-20 revolutions per minute. For proper mixing, about 25-30 revolutions are required in a well-designed mixer. The optimum mixing time depends on the type of the mixer, the condition of the mixer, the speed of rotation, the size of the charge and the nature of the constituent material.

The mixing time varies b/n 1-2 minutes. Bigger the capacity of the drum more is the mixing time. The quality of concrete in terms of compressive strength will increase with the increase in the time of mixing. But for mixing time beyond two minutes, the improvement in compressive strength is not very significant.

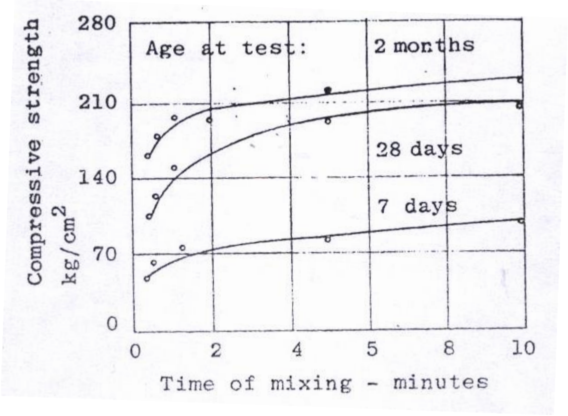


Fig: Effect of mixing time on strength of concrete

C. Transporting of concrete

Concrete can be transported by a variety of methods and equipment. The precaution to be taken while transporting concrete is that the homogeneity obtained at the time of mixing should be maintained while being transported to the final place of deposition. There are different ways of handling concrete, and the choice will depend mostly on the amount of concrete involved, the size and type of construction, the topography of the job site, the location of the batch plant and the relatively cost.

The methods adopted for transportation of concrete are

a) Mortar pan
b) Wheel barrow, hand cart
c) crane, bucket and rope way
d) Truck mixers and dumpers
e) belt conveyors
f) Chute
g) skip and hoist
h) Transit mixer
i) Pump and pipe line
j) Helicopter

Any method of transportation should protect the concrete from the effects of the weather, should not cause undue segregation by excessive jarring or shaking and should maintain concrete quality.

Wheelbarrow

Concrete buggy

Chute

(Concrete transported to lower level)

Bucket

(Large & massive construction. Handled by crane)

Concrete pump

(through pipe)

Power Buggy

Direct Chute Discharge

Crane and bucket

Tower Crane and bucket

Concrete Pump

Conveyor Belt

Concrete Pump

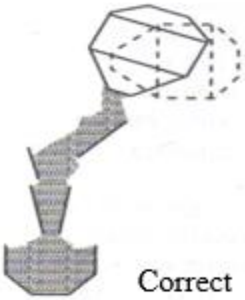
Helicopter for inaccessible site

D. Placing of concrete

It is of utmost importance that the concrete must be placed in a systematic manner to yield optimum results. As far as placing is concerned, the main objective is to deposit the concrete as close as possible to its final position so that the segregation is avoided and the concrete can be fully compacted. To achieve this objective, the following rules should be borne in mind.

- the concrete should be placed in uniform layers, not in large heaps or sloping layers;

- the rates of placing and compacting should be equal;
- where a good finish and uniform color are required on column and walls, forms should be filled at a rate of at least 2m per hour, avoiding delays (long delays can result in the formation of cold joints);
- each layer should be fully compacted before placing the one, and each subsequent layer should be placed whilst the underlying layer is still plastic so that monolithic construction is achieved;
- collision between concrete and formwork or reinforcement should be avoided. For deep section a long down pipe or termite ensures accuracy of location of the concrete and minimum segregation;
- concrete should be placed in a vertical plane. When placing in horizontal or sloping forms, the concrete should be placed vertically against, and not away from the previously placed concrete.



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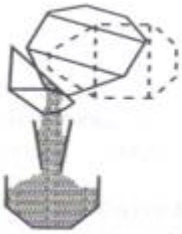

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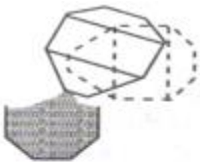

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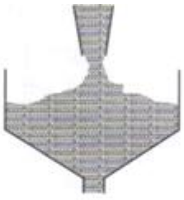

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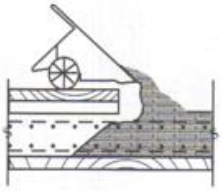

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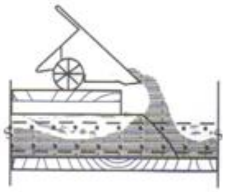

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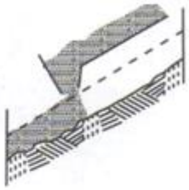

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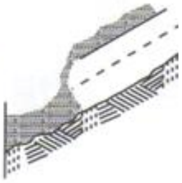

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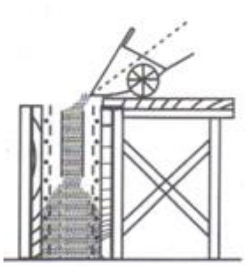

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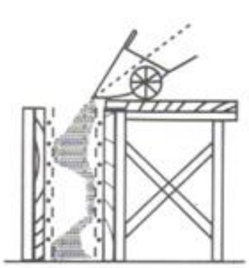

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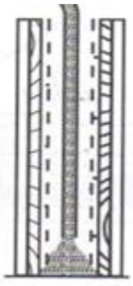

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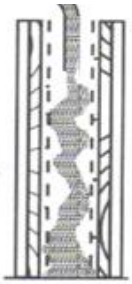

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E. Compaction

Compaction is one of the last, but important steps in concrete making, because the density, strength and durability of the concrete depend so much on it. Compaction of concrete is the process adopted for expelling the entrapped air from the concrete. If this entrapped air is not removed fully, the concrete loses strength considerably. 1 % entrapped air cause 5-6 % reduction in concrete strength. The following methods are adopted for compacting the concrete:

A. Hand compaction : Rodding, Ramming and Tamping
B. Compaction by vibration, Internal vibrator (needle vibrator), Formwork vibrator (external vibrator), Table vibrator, Platform vibrator, Surface vibrator (screed vibrator) and Vibratory roller
C. Compaction by pressure and jolting
D. Compaction by spinning

New filling shall be vibrated while the concrete is plastic, preferably within one hour. The duration of vibration is dependent on the height of the layer, the size and characteristic of the vibrator, and the workability of the concrete mix.

Vibrating rod (poker)

F. Curing of concrete

Moisture is necessary for the proper hardening of concrete because the chemical reaction that results in the setting and hardening of the paste takes place only in the presence of water. The loss of water by evaporation from the time the concrete is mixed and placed is usually so rapid that there may not be enough of it left for full hydration and hardening. Excessive loss of water due to evaporation may cause the hydration process to stop all together with a consequent reduced strength development. In addition, if concrete dries out too quickly by exposure to sun and wind, it will shrink. This early and usually rapid shrinkage will result in tensile stresses that will lead to surface cracks. It is important therefore that fresh concrete be kept moist for several days after placing. Curing can be described as keeping the concrete moist and warm enough so that the hydration of cement can continue. The purpose of curing can be summarized as follows:

i. Curing is to prevent formation of surface cracks due to rapid loss of water while the concrete is fresh and weak.
ii. To assure attainment of strength by providing enough moisture for the hydration of the cement grains throughout the concrete.

Curing methods may be divided broadly into four categories:

a. *Water curing:* This is by far the best method of curing as it satisfies all the requirement of curing, namely, promotion of hydration, elimination of shrinkage and absorption of the heat of hydration. Water curing can be done using the following methods; iimmersion, ponding, spraying or fogging and wet covering.

b. Membrane curing: Concrete could be covered with membrane which will effectively seal off the evaporation of water from the concrete.

c. Application of heat: When concrete is subjected to higher temperature it accelerates the hydration process resulting in faster development of strength. Subjecting the concrete to higher temperature and maintaining the required wetness can be achieved by subjecting the concrete to steam curing. It is most often used in prefabrication of concrete elements.

d. Miscellaneous method of curing: Calcium chloride is used either as surface coating or as an admixture. It has been satisfactorily used as curing medium. Calcium chloride being a salt, shows affinity for moisture. The salt, not only absorbs moisture from atmosphere but also retains it at the surface.

Spraying water or sealant - a chemical that forms a layer of membrane (film) that prevents evaporation

- Covering with wet gunny bags or polyethylene

Requirement of fresh concrete

For hardened concrete to be of an acceptable quality for a given job, the fresh concrete must satisfy the following requirements:

- It must be easily mixed and transported.
- It must be uniform throughout a given batch or b/n batches.

- It should have flow properties such that it is capable of completely filling the forms for which it was designed.
- It must have the ability to be compacted fully with out an excessive amount of energy being applied.
- It must not segregate during placing and consolidation.
- It must be capable of being finished properly, either against the forms or by means of trowelling or other surface treatment.

Workability

ASTM has defined workability as “property determining the effect required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity.”

ACI has defined workability as “the property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished. ”

Other definitions

- The property or group of properties which determines the ease with which a material can be used to give a product of the required properties.
- The combined effect of those properties of fresh concrete that determines the amount of work required for placement and compaction that determines the resistance to segregation.

Workability comprises three separate properties:

i. Compatibility or the ease with which the concrete can be compacted and the air voids be removed.

ii. Mobility or the ease with which concrete can flow into moulds, around reinforcing steel and be remoulded.

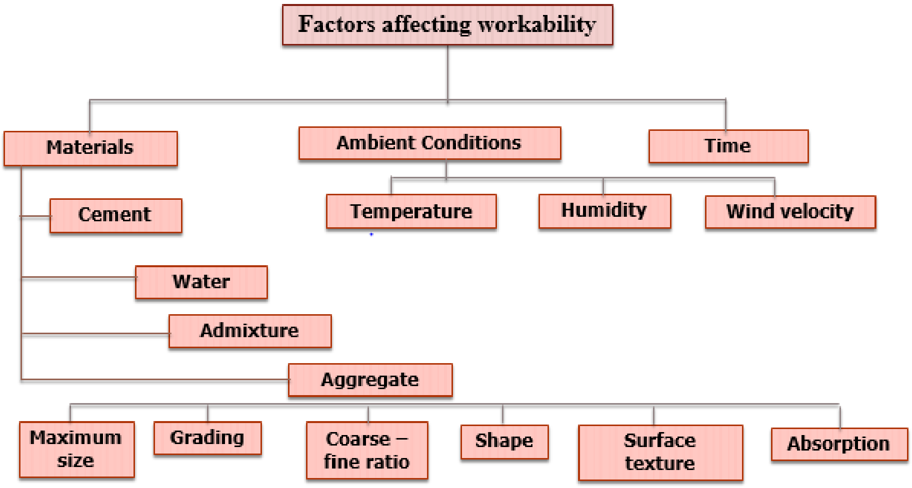
iii. Stability or the ability of concrete to remain a stable, coherent homogeneous mass during handling and vibration with out the constituents segregating.

Consistency

Consistency is the term used to denote the degree of fluidity or mobility of concrete. The degree of consistency of a concrete mixture can be described as stiff, plastic, and flowing.

Note: Every job requires a particular workability.

Factors affecting workability of concrete



Several factors affect the workability of concrete:

A. Water content: Water content in a given volume of concrete, will have significant influences on the workability. The higher the water content per cubic meter of concrete, the higher will be the fluidity of concrete.

B. Mix proportions: In case of rich concrete with lower aggregate/cement ratio, more paste is available to make the mix more workable.

C. Size of aggregate: For a given quantity of water and paste, bigger size of aggregates will give higher workability.

D. Shape of aggregates: Angular, elongated or flaky aggregates makes the concrete very harsh when compared to rounded aggregates or cubical shaped aggregates.

E. Surface texture: Rough textured aggregates will show poor workability and smooth or glassy textured aggregates will give better workability.

F. Grading of aggregates: This is one of the factor which will have maximum influence on workability. The better the grading, the less is the void content and higher the workability.

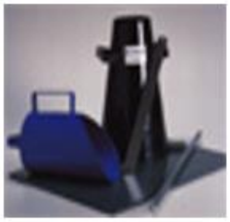
G. Use of admixtures: The plasticizers and superplasticizer greatly improve the workability by many folds.

H. Effect of environmental conditions: The workability of the concrete is also affected by the temperature of concrete and therefore, by the ambient temperature. The amount of mixing water required to bring about certain changes in the workability also increases with temperature.

I. Effect of time: Fresh concrete loses workability with time mainly because of the loss of moisture due to evaporation.

Measurement of workability

The following tests are commonly employed to measure workability:



Slump Test

Compacting factor test

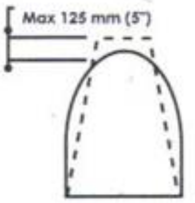
Vebe Time test

Flow test

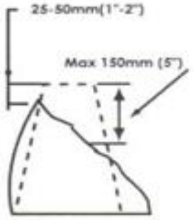
A. Slump test: it is the most commonly used method of measuring consistency of concrete which can be employed either in laboratory or site work. It is conveniently used as a control test and gives an indication of the uniformity of the concrete from batch to batch. It is not a suitable method for very wet or very dry concrete. It doesn’t measure all factors contributing to workability, nor it is always representative of the placability of concrete.

Three types of slumps can be observed:

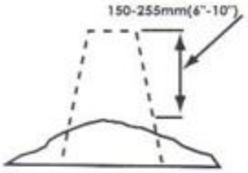
- True slump: the sample slumps evenly all around. These type of slump indicates a well proportioned concrete.
- Shear slump: part of the top cone might shear off and slide down an inclined plane. Shear slump indicates that the concrete is non cohesive and shows the characteristic of segregation.
- Collapse slump: the cone could completely collapse.



True slump

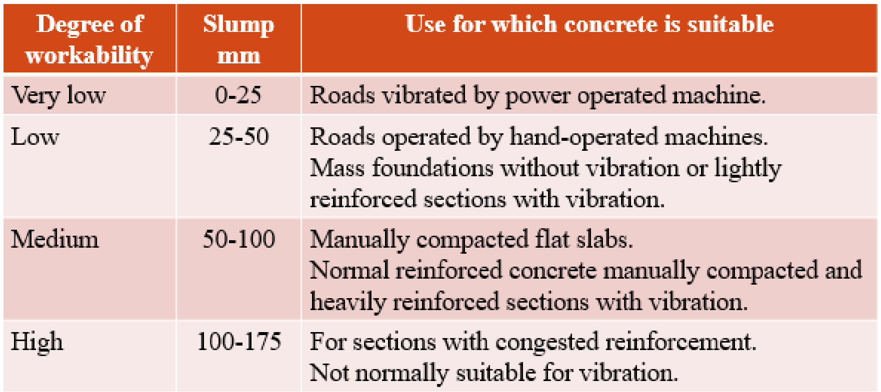


Shear slump



Collapse slump

Examples of the approximate ranges of slump for different workability.

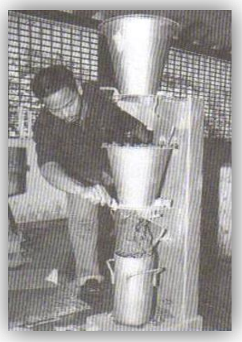


Degree of workability	Slump mm	Use for which concrete is suitable
Very low	0-25	Roads vibrated by power operated machine.
Low	25-50	Roads operated by hand-operated machines. Mass foundations without vibration or lightly reinforced sections with vibration.
Medium	50-100	Manually compacted flat slabs. Normal reinforced concrete manually compacted and heavily reinforced sections with vibration.
High	100-175	For sections with congested reinforcement. Not normally suitable for vibration.

B. Compaction factor test: Is used to determine the degree of compaction achieved by a standard amount of work. Concrete mixture is put in top hopper. Allowed to fall into 2nd hopper then to cylinder. Top of cylinder is struck off. Concrete is weighed. Compared with weight of fully compacted concrete in cylinder.

$$CF = \frac{\text{weight of partially compacted concrete}}{\text{weight of fully compacted concrete}}$$

(compacted in 4 layers, 25 x tampering each layer)



c. Vebe time test: Measures the work (time) needed to compact concrete. Very suitable for very dry concrete whose slump value can not be measured by slump test. The concrete is packed into a cone (similar to slump test). The cone stands within a special cylinder on a platform and lifted. The container is vibrated and the time taken for the concrete to be compacted flat by glass plate is Vebe time. Compared with weight of fully compacted concrete in cylinder.

D. Flow test: Gives an indication of the quality of concrete with respect to consistency, cohesiveness and the proneness to segregation. In this test, a standard mass of concrete is subjected to jolting. The spread or flow of the concrete is measured and the flow is related to workability.

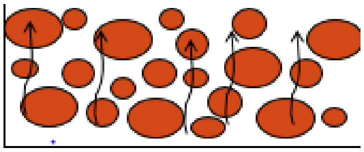
$$\text{Flow, \%} = \frac{\text{Spread diameter in cm} - 25}{25} \times 100$$

The value could range anything from 0 – 100%

Bleeding

When a newly placed concrete sets and consolidates part of its surplus water appears on the surface when the solids settle through the body of water. This tendency for water to rise in freshly placed concrete is known as bleeding or water gain. It results from the inability of the constituent materials to hold all the mixing water as the relatively heavy solids settle. The rising water tends to carry with it many fine particles which weakens the top portion and in extreme cases form a scum called "laitance" over the surface. Bleeding is predominantly observed in a highly wet mix, badly proportioned and insufficiently mixed concrete.

Note: Bleeding Cause weakness on concrete surface or develop line of weakness between pours.



Water while travelling from bottom to top, makes continuous channels. This continuous bleeding channels are often responsible for causing permeability of the concrete structures.

Bleeding rate increases with time up to about one hour or so and thereafter the rate decreases but continues more or less till the final setting time of cement. Bleeding is an inherent phenomenon. However, it can be reduced by proper proportioning, uniform and complete mixing, the use of finely divided pozollanic material, the use of air entraining agent, using cement with high C_3A content, using cement with lower alkali content and using rich mix.

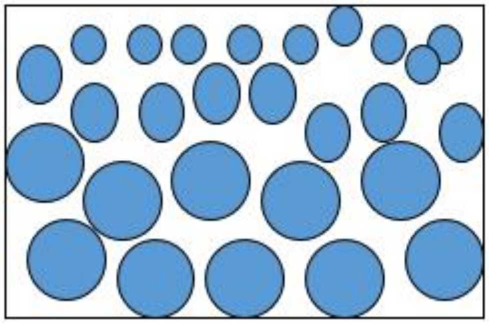
Segregation

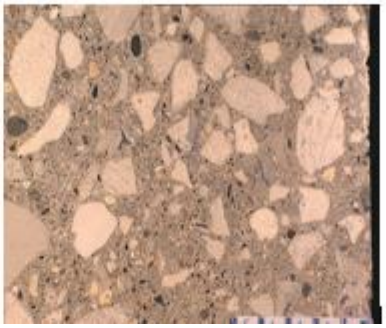
Segregation can be defined as the separation of the constituent materials of concrete. A good concrete is one in which all the ingredients are properly distributed to make a homogeneous mixture. Segregation may be of three types:

- The coarse aggregate separating out or settling down from the rest of the matrix.
- The paste separating away from coarse aggregate.
- Water separating out from the rest of the material.

Problem:

- Reduction in concrete strength
- Lack of homogeneity is also going to induce all undesirable properties in the hardened concrete
- Causes of segregation
- Badly proportioned mix where sufficient paste is not there to bind and contain the aggregates.
- Insufficiently mixed concrete.
- High workability (excess water content) or poor grading (excess coarse aggregate).
- Dropping fresh concrete from a height
- Conveyance of concrete by conveyor belt, wheel barrow, dumper, etc to a long distance.
- Excessive or inadequate vibration.





Heat of hydration and thermal cracks

Heat is liberated due to the exothermic chemical reaction between cement and water. In massive structures, the heat cannot be readily released causing high internal temperatures especially during hot weather. As the interior concrete increases in temperature and expands, the surface concrete may be cooling and contracting. If the temperature difference between the surface and the center is too great, thermal crack may occur or if the pour is restrained, crack due to drying shrinkage can occur.

Shrinkage and Creep

Shrinkage

Volume change is one of the most detrimental properties of concrete, which affects the long term strength and durability. The term shrinkage is loosely used to describe the various aspects of volume changes in concrete due to loss of moisture at different stages due to different reasons. Shrinkage can be classified in the following way:

i. Plastic Shrinkage

Shrinkage of this type manifests itself soon after the concrete is placed in the form while the concrete is still in the plastic state. Plastic shrinkage is considered to be reduction of volume of plastic concrete (typically during first 4 hours after placement). Loss of water by evaporation from the surface of concrete or absorption by the aggregate or subgrade, is believed to be the reason of plastic shrinkage. Plastic shrinkage can be reduced mainly by preventing the rapid loss of water.

(short, irregular cracks – more common in slabs, pavements)

Plastic shrinkage cracks are caused by a rapid loss of water from the surface of concrete while setting.

ii. Drying Shrinkage

Shrinkage due to drying of hardened concrete. The drying shrinkage of concrete is analogues to the mechanism of drying of timber specimen. The loss of free water contained in hardened concrete, does not result in any appreciable dimension change. It is the loss of water held in gel pores that cause the change in volume. Drying shrinkage of concrete is affected by:

- Unit water content,
- Cement content and quantity of the paste,
- Composition and fineness of cement,
- Type and grading of the aggregate,
- Size and shape of the concrete mass, and
- Curing condition.

Creep

Creep can be defined as the “time dependent” part of the strain resulting from stress. The gradual increase in strain, without increase in stress, with the time is due to creep. From this explanation creep can be defined as the increase in strain under sustained stress. Creep is a very gradual change in length (deformation) which occurs over time when a material is subjected to sustained load. Factors which influence creep are:

- Applied stress
- Temperature
- Chemical admixture
- W/c ratio
- Moisture
- Specimen geometry
- Curing condition
- Cement composition

The arch of Wade St Bridge, Bendigo (1901) has become almost flat in the centre. Creep in the concrete is probably the major factor.

Strength of concrete

Of the various strength properties of concrete it is generally the compressive strength which attracts the greatest interest. Since most concrete structures are designed to resist compressive stress, it is this property which usually prescribed by codes. The strength of concrete primarily depends up on the strength of cement paste. The strength of cement paste increases with cement content and decreases with air and water content. The strength of concrete is affected by a number of factors:

A. ***Effects of water/cement ratio and degree of compaction***: The water-cement ratio is the main factor affecting the compressive strength of concrete at all ages. Lower water/cement ratios lead to higher strengths. Every increase of 0.01 in the water-cement ratio decreases the strength by 1-1.5 N/mm^2.

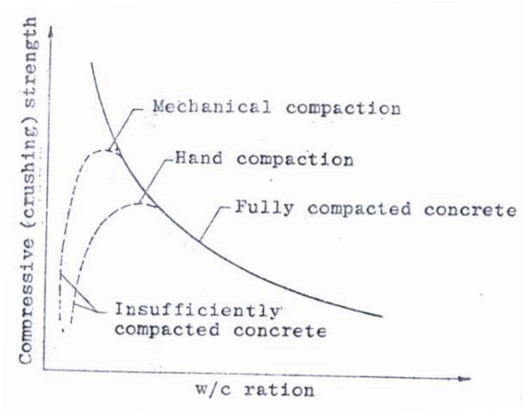
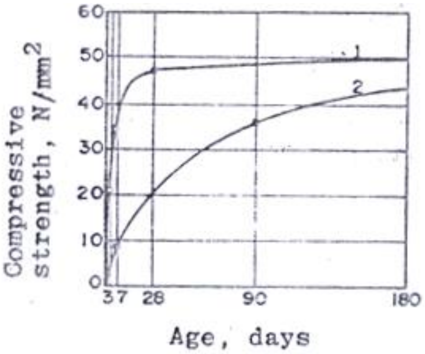


Fig: Relationship b/n strength and water/cement ratio

B. ***Effect of cement:*** The effect of cement on strength of concrete is dependent both on its type and quantity. The early strength of cement is related to tricalicium silicate (C_3S)

content – the higher the C_3S content relative to the C_2S content, more quickly the strength gained after mixing. Higher cement content increases strength and the heat generated. Finer cement causes faster hydration rate, more heat and faster strength development.

Storage of cement: The quality of cement stored in bags gradually deteriorates due to hydration. The loses in strength for different periods of storage are 15% in 3 months, 30% in 6 months, and 50% in a year.



Effect of C_3S/C_2S ratio on strength of cement mortar

1 mortar made with cement rich in C_3S and poor in C_2S.
2 mortar made with cement rich in C_2S and poor in C_3S

C. Effect of aggregates : For a constant water cement ratio and the same degree of compaction, the compressive strength of concrete decreases when the specific surface area of the aggregate increases. For the same cement content and degree of compaction, when the quantity of fine is increased, the demand for higher amount of water arises and consequently leads to a weaker concrete.

Size: Too large or too fine aggregate decrease strength.

Shape and Texture: Crushed or rough surface provides better early strength and similar long term strength as smooth aggregate.

Gradation: well grade aggregates insures better strength.

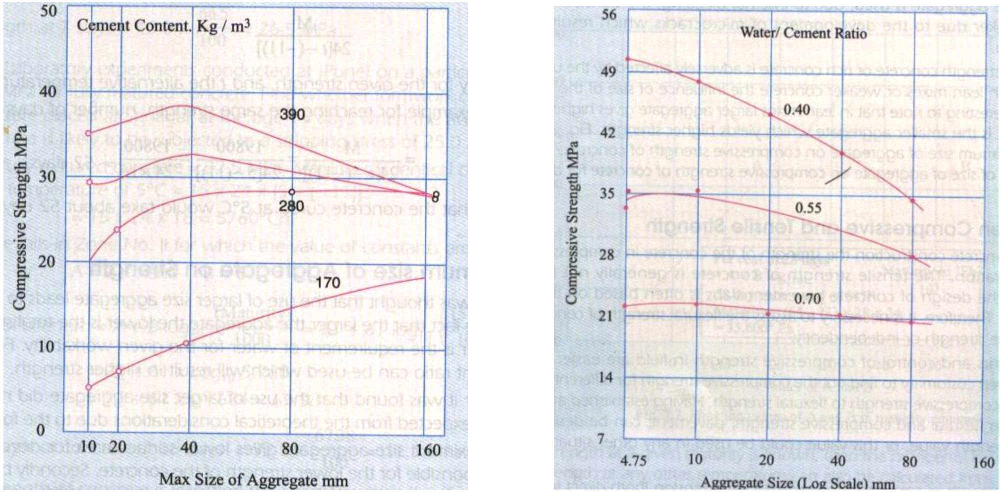


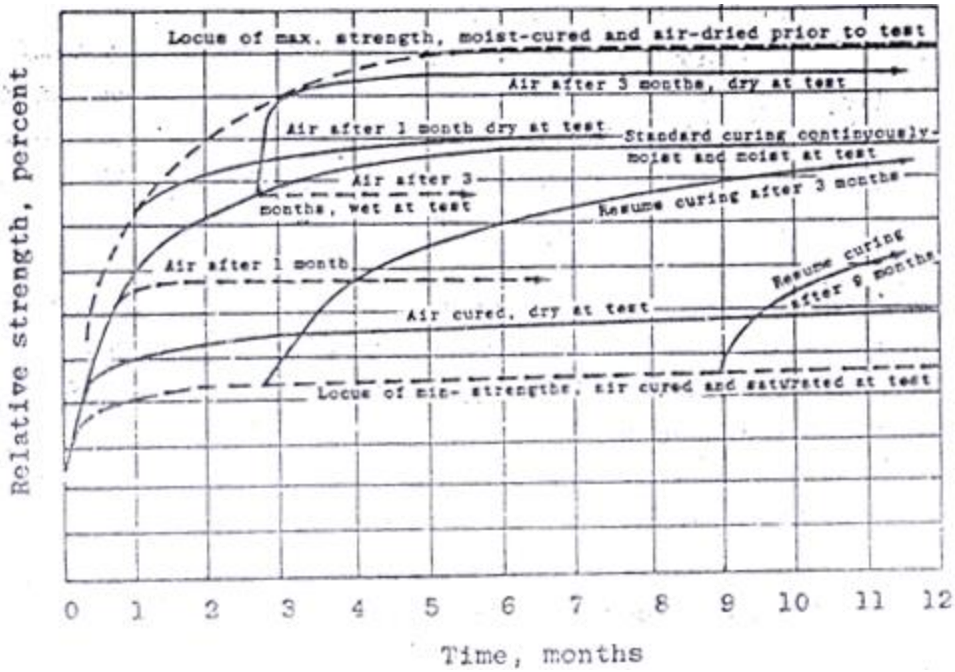
Fig: The influence of maximum size of aggregate on compressive strength

D. ***Effect of Age and curing condition:*** From an age of about 12 hours, the strength of concrete increases rapidly with time. Correlations between strength at different ages are important since they often form the basis of 28 day, or later, strength prediction, by testing at early ages.

Table: Strength ratios for 0.6 water/cement concrete at various ages

Age (days)	1	3	7	28	60	90	180
Strength	0.20	0.48	0.72	1.00	1.07	1.10	1.13

Best strength is ultimately obtained with concrete that is continuously moist cured. Without moist curing, potential strength may reduce by 50%.



- ***E. Effect of compaction:*** The presence of 1% voids in the mix reduces the strength of concrete by 5%. With improper compaction and 5% voids, a well proportioned concrete of strength 20 N/mm^2 would actually exhibit strength of 15 N/mm^2 only.

Factors Affecting the measured compressive strength are stress Distribution in Specimens, effect of l/d Ratio of cylinder specimen, specimen Geometry, rate of loading, moisture content, temperature at testing, direction of loading and duration of loading.

Durability of concrete

In practice, concrete is designed and constructed in order to build permanent structures. However, at times, its service life may be markedly reduced by the disintegrating effects of either the environment to which it is exposed or by internal causes within its mass. The durability of concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. Durable concrete will retain its original form, quality, and serviceability when exposed to its environment.

The environmental cause may be:

- Physical: Weathering due to the action of rain and freezing and thawing and also dimensional changes (expansion and contraction) resulting from temperature variations and/or alternate wetting and drying,
- Chemical: due to aggressive waters containing sulfates, leaching in hydraulic structures, and chemical corrosion.
- Mechanical wear: by abrasion from pedestrian or vehicular use, by wave action in structures along the seashore or erosion from the action of flowing water.

Two key factors affecting durability are compressive strength and permeability. Low strength and high permeability decrease durability.

Concrete testing: is conducted to ensure that the laboratory mix design was adequate, indicate the statistical variability in the properties of the concrete, reveal problems arising due to inadvertent changes, ensure that all parties in concrete production, do not become careless, important in carrying out quality control and compliance. Types of concrete tests:

A. Destructive test
    - Compression test
    - Beam bending strength test
    - Cylinder splitting test
    - Concrete core test

A. Non destructive test
    - Ultrasonic pulse velocity test
    - Rebound hammer test (Schmidt hammer test)
    - Cover-meter test
    - Gamma-ray test

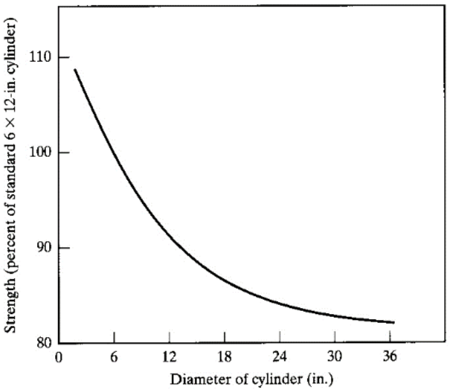
Compression tests

Why is compressive strength test the most common of all tests on hardened concrete?

- Most of the important properties of concrete are directly related to the compressive strength.
- The structural design codes are based mainly on the compressive strength.
- The test is easy and relatively inexpensive to carry out.
- Most of the quality control and compliance criteria adopt compressive strength.

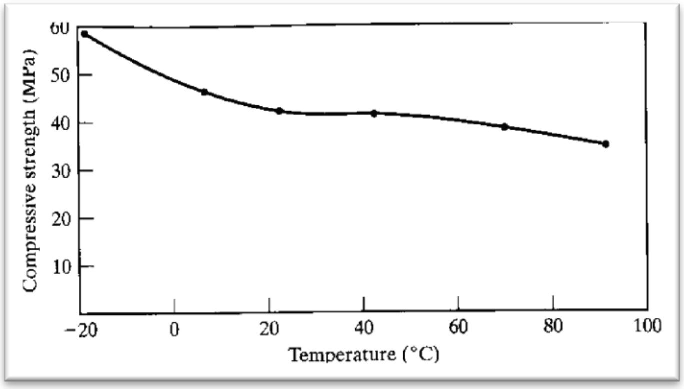
Factors Affecting the Measured compressive strength

Specimen Geometry: strength and the variability in strength of concrete decrease as the specimen size increases.



Rate of loading: The higher the rate of loading, the higher the measured strength.

Temperature at testing: The temperature of the specimen at the time of testing will affect the strength.



Moisture content: It has been found that concrete that has been dried shows an increase in strength.

CHAPTER 5: MIX DESIGN PROCESS

Introduction

The proportioning of concrete mixtures, more commonly referred to as mix design, is a process that consists of two interrelated steps:

- Selection of the suitable ingredients (cement, aggregate, water and admixtures) of concrete and
- Determining their relative quantities (“proportioning”) to produce, as economically as possible, concrete of the appropriate workability, strength and durability.

A. Economy: the cost of concrete is made up of the costs of materials, labor, and equipment. However, except for some special concretes, the costs of labor and equipment are largely independent of the type and quality of concrete produced. It is therefore the material costs that are most important in determining the relative costs of different mix designs. Since cement is much more expensive than aggregate, it is clear that minimizing the cement content is the most important single factor in reducing concrete costs. This can, in general, be done by using the lowest slump that will permit adequate placement, by using the largest practical maximum size of aggregate, by using the optimum ratio of coarse to fine aggregates, where necessary, by using appropriate admixtures.

B. Workability: a properly designed mix must be capable of being placed and compacted properly with the equipment available. Finishability must be adequate, and segregation and bleeding should be minimized. As a general rule, the concrete should be supplied at the minimum workability that will permit adequate placement. For concrete without mineral admixtures, the water requirement for workability depends mostly on the characteristics of the aggregate rather than those of the cement.

C. Strength and Durability: In general, concrete specification will require a minimum compressive strength. They may also impose limitations on the permissible w/c ratio and minimum cement contents. It is important to ensure that these requirements are not mutually incompatible. Specifications may also require that the concrete meet certain durability requirements, such as resistance to freezing and thawing or chemical attack.

Limiting Values: It is obvious to encounter limiting values in many specifications. The limiting values may cover a range of properties; the more usual ones areMinimum compressive strength necessary from structural considerations;

- Maximum water/cement ratio and/or minimum cement content and, in certain conditions of exposure, a minimum content of entrained air to give adequate durability;
- Maximum cement content to avoid cracking due to the temperature cycle in mass concrete;
- Maximum cement content to avoid shrinkage cracking under conditions of exposure to a low humidity; and
- Minimum density for gravity dams and similar structures.

Mix Design Methods: Some of the prevalent concrete mix design methods are:

- ACI: American Concrete Institute Mix Design Method,
- DOE: Department of Environment Mix design practice (British),
- DIN Mix design Method (German)
- IS: Indian Standard Mix Design Method

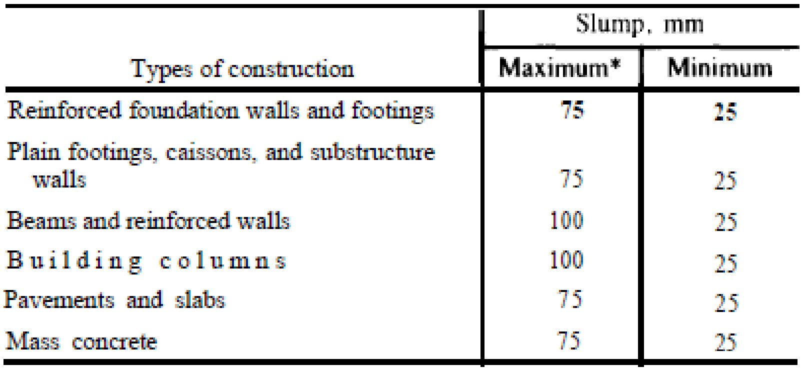
ACI mix design process

To the extent possible, selection of concrete proportions should be based on test data or experience with the materials actually to be used. The following information for available materials will be useful; sieve analyses of fine and coarse aggregates, unit weight of coarse aggregate, bulk specific gravities and absorptions of aggregates, specific gravities of Portland cement and other cementitious materials, if used. Optimum combination of coarse aggregates to meet the maximum density grading.

Procedure

Step-1: Choice of slump

If slump is not specified, a value appropriate for the work can be selected from Table-1



Types of construction	Slump, mm	
	Maximum*	Minimum
Reinforced foundation walls and footings	75	25
Plain footings, caissons, and substructure walls	75	25
Beams and reinforced walls	100	25
Building columns	100	25
Pavements and slabs	75	25
Mass concrete	75	25

Table-1: Recommended slumps for various types of construction

Step-2: Choice of maximum size of aggregate

Large nominal maximum sizes of well graded aggregates have less voids than smaller sizes. Hence, concretes with the larger-sized aggregates require less mortar per unit volume of concrete. Generally, the nominal maximum size of aggregate should be the largest that is economically available and consistent with dimensions of the structure.

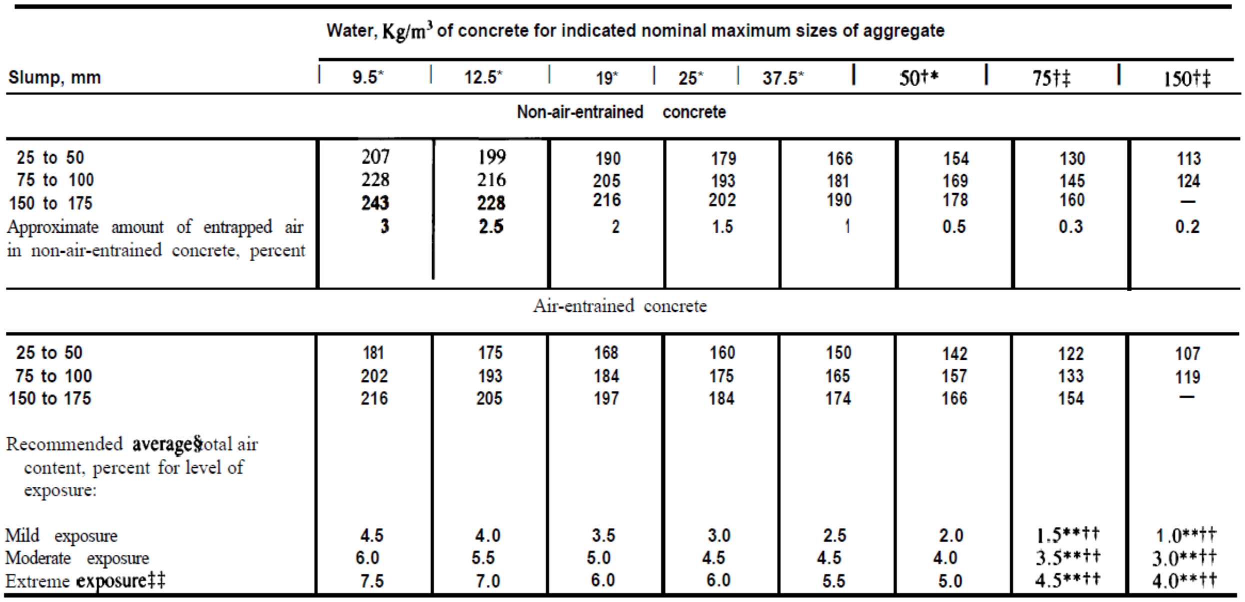
Step-3: Estimation of mixing water and air content

The quantity of water per unit volume of concrete required to produce a given slump is dependent on the nominal maximum size, particle shape, grading of the aggregates;

- the concrete temperature;
- the amount of entrained air; and
- use of chemical admixtures.

Table-2 provides estimates of required mixing water for concrete made with various maximum sizes of aggregate, with and without air entrainment.

Table-2: Approximate mixing water and air content requirements

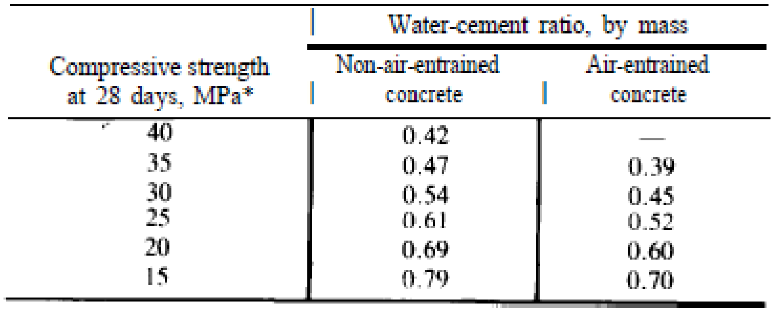


Slump, mm	9.5*	12.5*	19*	25*	37.5*	50†*	75†‡	150†‡
	Water, Kg/m^3 of concrete for indicated nominal maximum sizes of aggregate							
	Non-air-entrained concrete							
25 to 50	207	199	190	179	166	154	130	113
75 to 100	228	216	205	193	181	169	145	124
150 to 175	243	228	216	202	190	178	160	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
	Air-entrained concrete							
25 to 50	181	175	168	160	150	142	122	107
75 to 100	202	193	184	175	165	157	133	119
150 to 175	216	205	197	184	174	166	154	—
Recommended average§otal air content, percent for level of exposure:								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5**††	1.0**††
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5**††	3.0**††
Extreme exposure‡‡	7.5	7.0	6.0	6.0	5.5	5.0	4.5**††	4.0**††

Step-4: Selection of water-cement or water-cementitious materials ratio

Approximate and relatively conservative values for concrete containing Type I Portland cement can be taken from Table-3a.

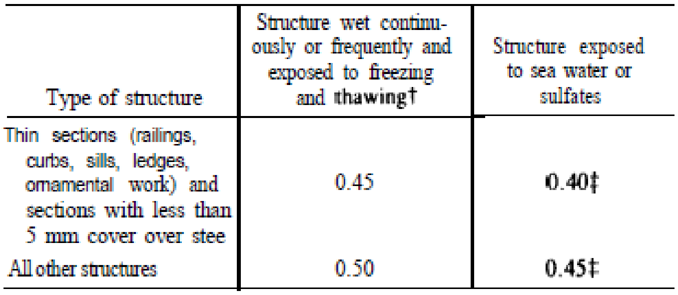
Table-3a: Relationships between water-cement ratio and compressive strength of concrete



Compressive strength at 28 days, MPa*	Water-cement ratio, by mass Non-air-entrained concrete	Air-entrained concrete
40	0.42	—
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.60
15	0.79	0.70

For severe conditions of exposure, the w/c or w/(c + p) ratio should be kept low even though strength requirements may be met with a higher value. Table-3b gives limiting values.

Table-3b: Maximum permissible water-cement ratios for concrete in severe exposure



Type of structure	Structure wet continuously or frequently and exposed to freezing and thawing†	Structure exposed to sea water or sulfates
Thin sections (railings, curbs, sills, ledges, ornamental work) and sections with less than 5 mm cover over stee	0.45	0.40‡
All other structures	0.50	0.45‡

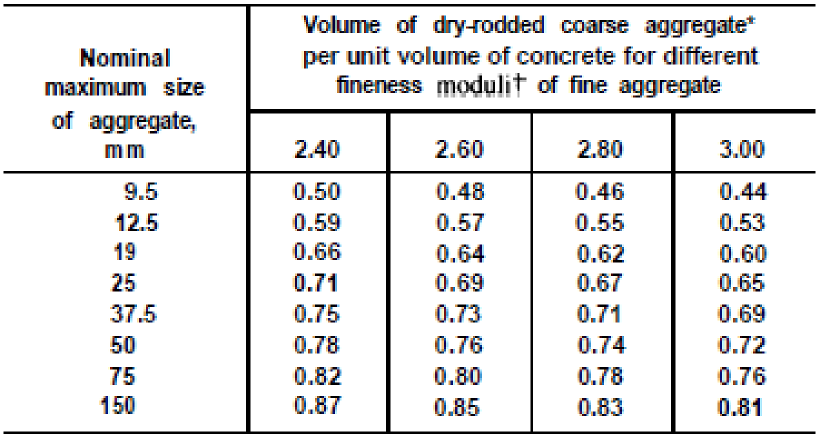
Step-5: Calculation of cement content

The amount of cement per unit volume of concrete is fixed by the determinations made in Steps 3 and 4 above. The required cement is equal to the estimated mixing-water content (Step 3) divided by the water-cement ratio (Step 4). If, however, the specification includes a separate minimum limit on cement in addition to requirements for strength and durability, the mixture must be based on whichever criterion leads to the larger amount of cement.

Step-6: Estimation of coarse aggregate content

Appropriate values for this aggregate volume are given in Table-4.

Table-4: Volume of coarse aggregate per unit volume of concrete



Nominal maximum size of aggregate, mm	Volume of dry-rodded coarse aggregate* per unit volume of concrete for different fineness moduli† of fine aggregate			
	2.40	2.60	2.80	3.00
9.5	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
19	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
75	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

Step-7: Estimation of fine aggregate content

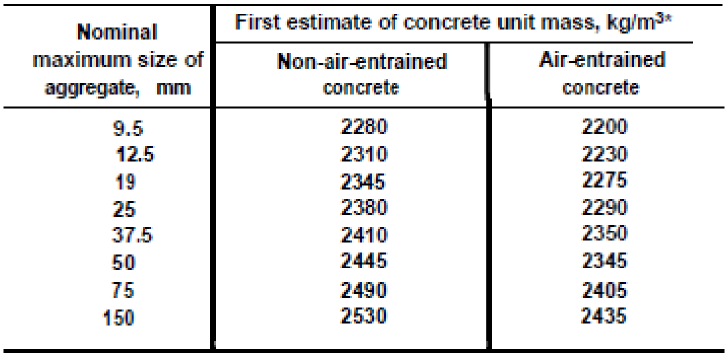
At completion of Step 6, all ingredients of the concrete have been estimated except the fine aggregate. Its quantity is determined by difference. Either of two procedures may be employed:

- the weight method or the absolute volume method.

<u>The weight method:</u> If the weight of the concrete per unit volume is assumed or can be estimated from experience, the required weight of fine aggregate is simply the difference between the weight of fresh concrete and the total weight of the other ingredients.

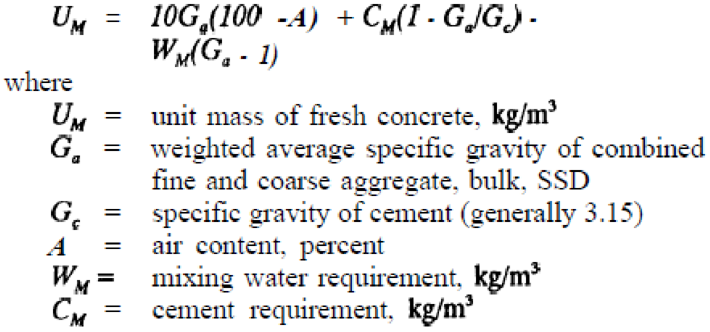
First estimate of weight of fresh concrete can be determined from Table- 5.

Table-5: First estimate of weight of fresh concrete



Nominal maximum size of aggregate, mm	First estimate of concrete unit mass, kg/m³*	
	Non-air-entrained concrete	Air-entrained concrete
9.5	2280	2200
12.5	2310	2230
19	2345	2275
25	2380	2290
37.5	2410	2350
50	2445	2345
75	2490	2405
150	2530	2435

If a theoretically exact calculation of fresh concrete weight per m^3 is desired, the following formula can be used.



$$U_M = 10G_a(100 - A) + C_M(1 - G_a/G_c) - W_M(G_a - 1)$$

where

U_M = unit mass of fresh concrete, **kg/m³**
G_a = weighted average specific gravity of combined fine and coarse aggregate, bulk, SSD
G_c = specific gravity of cement (generally 3.15)
A = air content, percent
W_M = mixing water requirement, **kg/m³**
C_M = cement requirement, **kg/m³**

Step-8: Adjustment for moisture aggregate

The aggregate quantities actually to be weighed out for the concrete must allow for moisture in the aggregates. Generally, the aggregates will be moist and their dry weights should be increased by the percentage of water they contain, both absorbed and surface. The mixing water added to the batch must be reduced by an amount equal to the free moisture contributed by the aggregate -- i.e., total moisture minus absorption.

Step-9: Trial batch adjustments

The calculated mixture proportions should be checked by means of trial batches prepared and tested in accordance with ASTM C 192

Example-1

Concrete is required for a portion of a structure that will be below ground level in a location where it will not be exposed to severe weathering or sulfate attack. Structural considerations require it to have an average 28-day compressive strength of 24 Mpa (cylindrical). It is determined that under the conditions of placement to be employed, a slump of 75-100 mm should be used. and the coarse aggregate has a nominal maximum size of 37.5 mm and dry-rodded mass of 1600 kg/m^3.

- Other properties of the ingredients are: cement -Type I with specific gravity of 3.15; coarse aggregate - bulk specific gravity 2.68 and absorption 0.5 percent; fine aggregate - bulk specific gravity 2.64, absorption 0.7 percent, and fineness modulus 2.8.
- Calculate the weights of all materials that you would use for the first trial mix on a concrete mix.

Solution

Step 1: The slump is required to be 75 to 100 mm.

Step 2: The aggregate to be used has a nominal maximum size of 37.5 mm.

Step 3: The concrete will be non-air entrained since the structure is not exposed to severe weathering. From Table-2, the estimated mixing water for a slump of 75 to 100 mm in non-air-entrained concrete made with 37.5 mm aggregate is found to be 181 kg/m^3.

Step 4: The water-cement ratio for non-air entrained concrete with a strength of 24 MPa is found from Table-3a to be 0.62.

Step-5: From the information developed in Steps 3 and 4, the required cement content is found to be 181/0.62 = 292 kg/m^3.

Step 6: The quantity of coarse aggregate is estimated from Table-4. For a fine aggregate having a fineness modulus of 2.8 and a 37.5 mm nominal maximum size of coarse aggregate, the table indicates that 0.71 m^3 of coarse aggregate, on a dry-rodded basis, may be used in each cubic meter of concrete.

- The required dry mass is, therefore, 0.71 x 1600 = 1136 kg.

Step 7: The required fine aggregate may be determined on the basis of either mass or absolute volume as shown below:

Mass basis: From Table-5, the mass of a cubic meter of non-air-entrained concrete made with aggregate having a nominal maximum size of 37.5 mm is estimated to be 2410 kg. Masses already known are:

Water (net mixing)	181 kg
Cement	292 kg
Coarse aggregate	1136 kg
Total	1609 kg

The mass of fine aggregate is therefore estimated to be

2410 – 1609 = 801Kg

Absolute volume basis: With the quantities of cement, water, and coarse aggregate established, and the approximate entrapped air content of 1 percent determined from Table-2 , the sand content can be calculated as follows:

Volume of water	=	$\frac{181}{1000}$	0.181 m^3
Solid volume of cement	=	$\frac{292}{3.15 \times 1000}$	0.093 m^3
Solid volume of coarse aggregate	=	$\frac{1136}{2.68 \times 1000}$	0.424 m^3
Volume of entrapped air	=	0.01 x 1.000	0.010 m^3
Total solid volume of ingredients except fine aggregate			0.708 m^3
Solid volume of fine aggregate required	=	1.000 - 0.705	0.292 m^3
Required weight of dry fiie aggregate	=	0.292 x 2.64 x 1000	771 kg

Batch masses per cubic meter of concrete calculated on the two bases are compared below:

	Based on estimated concrete mass, kg	Based on absolute volume of ingredients, kg
Water (net mixing)	181	181
Cement	292	292
Coarse aggregate (dry)	1136	1136
Sand (dry)	801	771

Step 8: Tests indicate total moisture of 2 percent in the coarse aggregate and 6 percent in the fine aggregate. If the trial batch proportions based on assumed concrete mass are used, the adjusted aggregate masses become

Coarse aggregate (wet) = 1136(1.02) = 1159 kg
Fine aggregates (wet) = 801(1.06) = 849kg

Absorbed water does not become part of the mixing water and must be excluded from the adjustment in added water. Thus, surface water contributed by the coarse aggregate amounts to 2 - 0.5 = 1.5%; by the fine aggregate 6 - 0.7 = 5.3%. The estimated requirement for added water, therefore, becomes

$$181 - 1136(0.015) - 801(0.053) = 122 \text{ kg}$$

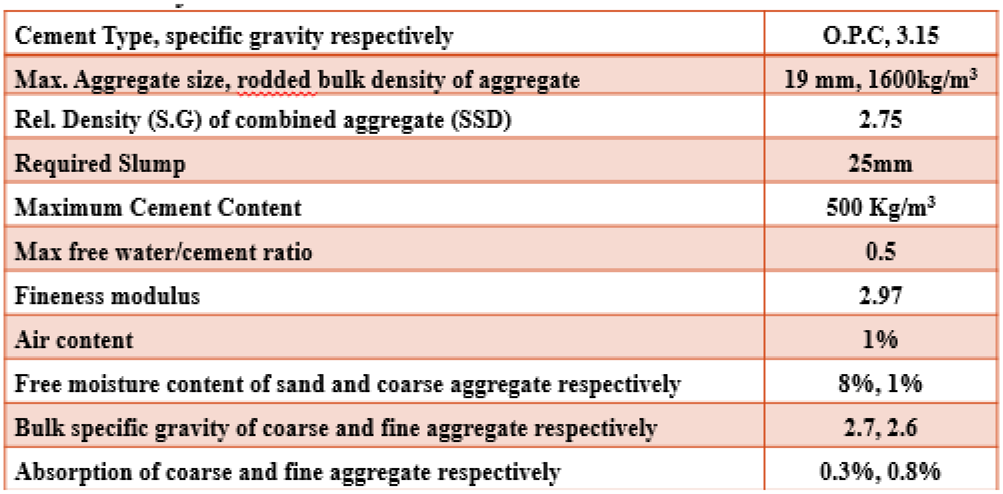
The estimated batch masses for a cubic meter of concrete are:

Water (to be added)	122 kg
Cement	292 kg
Coarse aggregate (wet)	1159 kg
Fine aggregate (wet)	849 kg
Total	2422 kg

Step 9: For the laboratory trial batch, it is found convenient to scale the masses down to produce 0.02 m^3 of concrete.

Review exercise-1

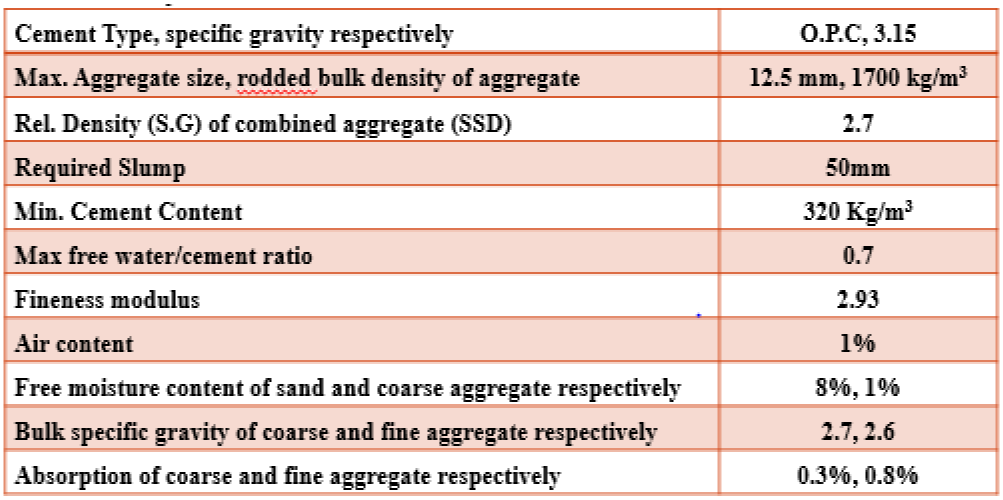
Calculate the weights of all materials that you would use for the first trial mix on a concrete mix required to achieve Characteristic compressive strength of 25 N/mm^2 at 28 days (cubic strength). The following information on material properties and plant performance is available to you.



Cement Type, specific gravity respectively	O.P.C, 3.15
Max. Aggregate size, rodded bulk density of aggregate	19 mm, 1600kg/m^3
Rel. Density (S.G) of combined aggregate (SSD)	2.75
Required Slump	25mm
Maximum Cement Content	500 Kg/m^3
Max free water/cement ratio	0.5
Fineness modulus	2.97
Air content	1%
Free moisture content of sand and coarse aggregate respectively	8%, 1%
Bulk specific gravity of coarse and fine aggregate respectively	2.7, 2.6
Absorption of coarse and fine aggregate respectively	0.3%, 0.8%

Review exercise-2

Calculate the weights of all materials that you would use for the first trial mix on a concrete mix required to achieve Characteristic compressive strength of 40 N/mm^2 at 28 days (cubic strength). The following information on material properties and plant performance is available to you.



Cement Type, specific gravity respectively	O.P.C, 3.15
Max. Aggregate size, rodded bulk density of aggregate	12.5 mm, 1700 kg/m^3
Rel. Density (S.G) of combined aggregate (SSD)	2.7
Required Slump	50mm
Min. Cement Content	320 Kg/m^3
Max free water/cement ratio	0.7
Fineness modulus	2.93
Air content	1%
Free moisture content of sand and coarse aggregate respectively	8%, 1%
Bulk specific gravity of coarse and fine aggregate respectively	2.7, 2.6
Absorption of coarse and fine aggregate respectively	0.3%, 0.8%